JOURNAL

OF THE

FRANKLIN INSTITUTE.

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXI. JUNE, 1881. No. 6.

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PRODUCTION OF SOUND BY RADIANT ENERGY.

By ALEXANDER GRAHAM BELL.

A paper read before the National Academy of Arts and Sciences April 21, 1881.

In a paper read before the American Association for the Advancement of Science last August, I described certain experiments made by Mr. Sumner Tainter and myself which had resulted in the construction of a "Photophone," or apparatus for the production of sound by light;* and it will be my object to-day to describe the progress we have made in the investigation of photophonic phenomena since the date of this communication.

In my Boston paper the discovery was announced that thin disks of very many different substances *emitted sounds* when exposed to the action of a rapidly-interrupted beam of sunlight. The great variety of material used in these experiments led me to believe that sonorousness under such circumstances would be found to be a general property of all matter.

At that time we had failed to obtain audible effects from masses of

*Proceedings of the American Association for the Advancement of Science, Aug. 27, 1880; see also *American Journal of Science*, vol. xx, p. 305; *Journal of the American Electrical Society*, vol. iii, p. 3; *Journal of the Society of Telegraph Engineers and Electricians*, vol. ix, p. 404; *Annales de Chimie et de Physique*, vol. xxi.

the various substances which became sonorous in the condition of thin diaphragms; but this failure was explained upon the supposition that the molecular disturbance produced by the light was chiefly a surface action, and that under the circumstances of the experiments the vibration had to be transmitted through the mass of the substance in order to affect the ear. It was therefore supposed that if we could lead to the ear air that was directly in contact with the illuminated surface, louder sounds might be obtained, and solid masses be found to be as sonorous as thin diaphragms. The first experiments made to verify this hypothesis pointed towards success. A beam of sunlight was focussed into one end of an open tube, the ear being placed at the other end. Upon interrupting the beam a clear musical tone was heard, the pitch of which depended upon the frequency of the interruption of the light and the loudness upon the material composing the tube. At this stage our experiments were interrupted, as circumstances called me to Europe.

While in Paris a new form of the experiment occurred to my mind, which would not only enable us to investigate the sounds produced by masses, but would also permit us to test the more general proposition that *sonorousness, under the influence of intermittent light, is a property common to all matter.*

The substance to be tested was to be placed in the interior of a transparent vessel, made of some material which (like glass) is transparent to light, but practically opaque to sound.

Under such circumstances the light could get in, but the sound produced by the vibration of the substance could not get out. The audible effects could be studied by placing the ear in communication with the interior of the vessel by means of a hearing-tube.

Some preliminary experiments were made in Paris to test this idea, and the results were so promising that they were communicated to the French Academy on the 11th of October, 1880, in a note read for me by Mr. Antoine Breguet.* Shortly afterwards I wrote to Mr. Tainter, suggesting that he should carry on the investigation in America, as circumstances prevented me from doing so myself in Europe. As these experiments seem to have formed the common starting-point for a series of independent researches of the most important character carried on simultaneously in America by Mr. Tainter, and in Europe by M.

* *Comptes Rendus*, vol. xci, p. 595.

Mercadier,* Prof. Tyndall,† W. E. Röntgen,‡ and W. H. Preece,§ I may be permitted to quote from my letter to Mr. Tainter the passage describing the experiments referred to:

"METROPOLITAN HOTEL, RUE CAMBON, PARIS, Nov. 2, 1880.

"DEAR MR. TAINTER—* * * * I have devised a method of producing sounds by the action of an intermittent beam of light from substances that cannot be obtained in the shape of thin diaphragms or in the tubular form; indeed, the method is specially adapted to testing the generality of the phenomenon we have discovered, as it can be adapted to solids, liquids and gases.

"Place the substance to be experimented with in a glass test-tube, connect a rubber tube with the mouth of the test-tube, placing the other end of the pipe to the ear. Then focus the intermittent beam upon the substance in the tube. I have tried a large number of substances in this way with great success, although it is extremely difficult to get a glimpse of the sun here, and when it does shine the intensity of the light is not to be compared with that to be obtained in Washington. I got splendid effects from crystals of bichromate of potash, crystals of sulphate of copper, and from tobacco smoke. A whole cigar placed in the test-tube produced a very loud sound. I could not hear anything from plain water, but when the water was discolored with ink a feeble sound was heard. I would suggest that you might repeat these experiments and extend the results," etc.

Upon my return to Washington, in the early part of January,‖ Mr. Tainter communicated to me the results of the experiments he had made in my laboratory during my absence in Europe. He had commenced by examining the sonorous properties of a vast number of substances enclosed in test-tubes in a simple empirical search for loud effects. He was thus led gradually to the discovery that cotton-wool, worsted, silk, and fibrous materials generally, produced much louder sounds than hard, rigid bodies like crystals, or diaphragms such as we had hitherto used.

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*"Notes on Radiophony," *Comptes Rendus*, Dec. 6 and 13, 1880; Feb. 21 and 28, 1881. See also *Journal de Physique*, vol. x, p. 53.

†"Action of an Intermittent Beam of Radiant Heat upon Gaseous Matter," *Proc. Royal Society*, Jan. 13, 1881, vol. xxxi, p. 307. [Reprinted in JOURNAL, p. 297.]

‡"On the Tones which Arise from the Intermittent Illumination of a Gas." See *Annalen der Phys. und Chemie*, Jan., 1881, No. 1, p. 155.

§"On the Conversion of Radiant Energy into Sonorous Vibrations." *Proc. Royal Society*, March 10, 1881, vol. xxxi, p. 506.

‖On the 7th of January.

In order to study the effects under better circumstances he enclosed his materials in a conical cavity in a piece of brass, closed by a flat plate of glass. A brass tube leading into the cavity served for connection with the hearing tube. When this conical cavity was stuffed with worsted or other fibrous materials the sounds produced were much louder than when a test-tube was employed. This form of receiver is shown in Fig. 1.

Fig. 1.

Mr. Tainter next collected silks and worsteds of different colors, and speedily found that the darkest shades produced the best effects. Black worsted, especially, gave an extremely loud sound. As white cotton-wool had proved itself equal, if not superior, to any other white fibrous material before tried, he was anxious to obtain colored specimens for comparison. Not having any at hand, however, he tried the effect of darkening some cotton-wool with lamp-black. Such a marked reinforcement of the sound resulted that he was induced to try lamp-black alone. About a teaspoonful of lamp-black was placed in a test-tube and exposed to an intermittent beam of sunlight. The sound produced was much louder than any heard before. Upon smoking a piece of plate-glass, and holding it in the intermittent beam with the lamp-black surface towards the sun, the sound produced was loud enough to be heard, with attention, in any part of the room. With the lamp-black surface turned from the sun the sound was much feebler.

Mr. Tainter repeated these experiments for me immediately upon my return to Washington, so that I might verify his results.

Upon smoking the interior of the conical cavity, shown in Fig. 1,

and then exposing it to the intermittent beam, with the glass lid in position as shown, the effect was perfectly startling. The sound was so loud as to be actually painful to an ear placed closely against the end of the hearing-tube. The sounds, however, were sensibly louder when we placed some smoked wire gauze in the receiver, as illustrated in the drawing, Fig. 1.

When the beam was thrown into a resonator, the interior of which had been smoked over a lamp, most curious alternations of sound and silence were observed. The interrupting disk was set rotating at a high rate of speed, and was then allowed to come gradually to rest. An extremely feeble musical tone was at first heard, which gradually fell in pitch as the rate of interruption grew less. The loudness of the sound produced varied in the most interesting manner. Minor reinforcements were constantly occurring, which became more and more marked as the true pitch of the resonator was neared. When at last the frequency of interruption corresponded to the frequency of the fundamental of the resonator, the sound produced was so loud that it might have been heard by an audience of hundreds of people.

The effects produced by lamp-black seemed to me to be very extraordinary, especially as I had a distinct recollection of experiments made in the summer of 1880 with smoked diaphragms, in which no such reinforcement was noticed.

Upon examining the records of our past photophonic experiments we found in vol. vii, p. 57, the following note:

"Experiment V.—Mica diaphragm covered with lamp-black on side exposed to light.

"Result: Distinct sound about same as without lamp-black.—*A. G. B.*, July 18th, 1880.

"Verified the above, but think it somewhat louder than when used without lamp-black."—*S. T.*, July 18th, 1880.

Upon repeating this old experiment we arrived at the same result as that noted. Little, if any, augmentation of sound resulted from smoking the mica. In this experiment the effect was observed by placing the mica diaphragm against the ear, and also by listening through a hearing-tube, one end of which was closed by the diaphragm. The sound was found to be more audible through the free air when the ear was placed as near to the lamp-black surface as it could be brought without shading it.

At the time of my communication to the American Association I

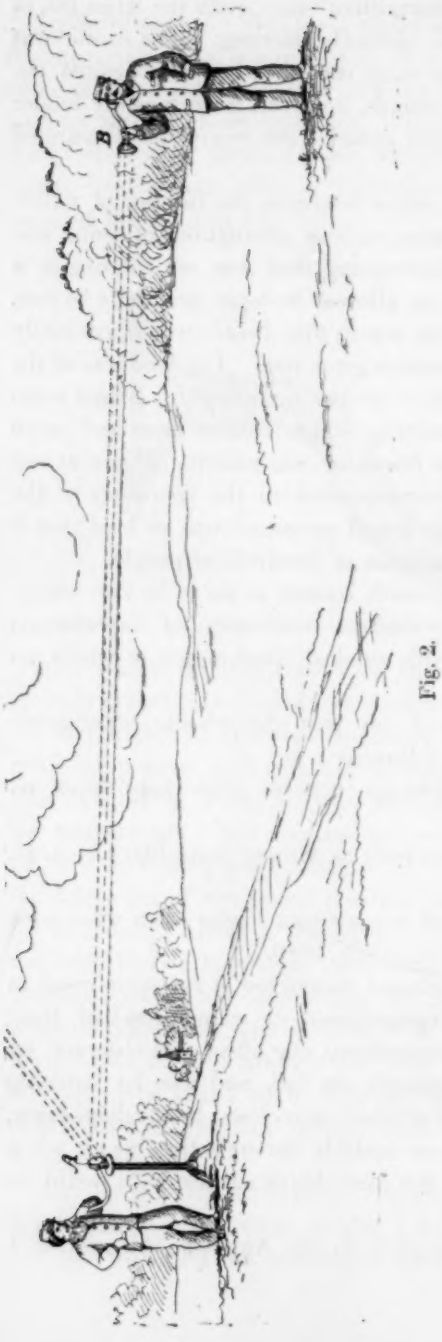


Fig. 2.

had been unable to satisfy myself that the substances which had become sonorous under the direct influence of intermittent sunlight were capable of reproducing the sounds of articulate speech under the action of an undulatory beam from our photophonic transmitter. The difficulty in ascertaining this will be understood by considering that the sounds emitted by thin diaphragms and tubes were so feeble that it was impracticable to produce audible effects from substances in these conditions at any considerable distance away from the transmitter; but it was equally impossible to judge of the effects produced by our articulate transmitter at a short distance away because the speaker's voice was directly audible through the air. The extremely loud sounds produced from lampblack have enabled us to demonstrate the feasibility of using this substance in an articulating photophone in place of the electrical receiver formerly employed.

The drawing (Fig. 2) illustrates the mode in which the experiment was conducted. The diaphragm of the transmitter (A) was only 5

centimetres in diameter, the diameter of the receiver (B) was also 5 centimetres, and the distance between the two was 40 metres, or 800 times the diameter of the transmitting diaphragm. We were unable to experiment at greater distances without a heliostat on account of the difficulty of keeping the light steadily directed on the receiver. Words and sentences spoken into the transmitter in a low tone of voice were audibly reproduced by the lamp-black receiver.

In Fig. 3 is shown a mode of interrupting a beam of sunlight for producing distant effects without the use of lenses. Two similarly perforated disks are employed, one of which is set in rapid rotation, while the other remains stationary. This form of interrupter is also admirably adapted for work with artificial light. The receiver illustrated in the drawing consists of a parabolic reflector, in the focus of which is placed a glass vessel (A) containing lamp-black or other sensitive substance, and connected with a hearing-tube. The beam of light is interrupted by its passage through the two slotted disks shown at B, and in operating the instrument musical signals like the dots and dashes of the Morse alphabet are produced from the sensitive receiver (A) by slight motions of the mirror (C) about its axis (D).

In place of the parabolic reflector shown in the figure a conical reflector like that recommended by Prof. Sylvanus Thompson * can be used, in which case a cylindrical glass vessel would be preferable to the flask (A) shown in the figure.

In regard to the sensitive materials that can be employed, our experiments indicate that in the case of solids the physical condition and the color are two conditions that markedly influence the intensity of the sonorous effects. *The loudest sounds are produced from substances in a loose, porous, spongy condition, and from those that have the darkest or most absorbent colors.*

The materials from which the best effects have been produced are cotton-wool, worsted, fibrous materials generally, cork, sponge, platinum, and other metals in a spongy condition, and lamp-black.

The loud sounds produced from such substances may perhaps be explained in the following manner: Let us consider, for example, the case of lamp-black, a substance which becomes heated by exposure to rays of all refrangibility. I look upon a mass of this substance as a sort of sponge, with its pores filled with air instead of water. When a beam of sunlight falls upon this mass the particles of lamp-black are

* *Phil. Mag.*, April, 1881, vol. xi, p. 286.

heated, and consequently expand, causing a contraction of the air-spaces or pores among them.

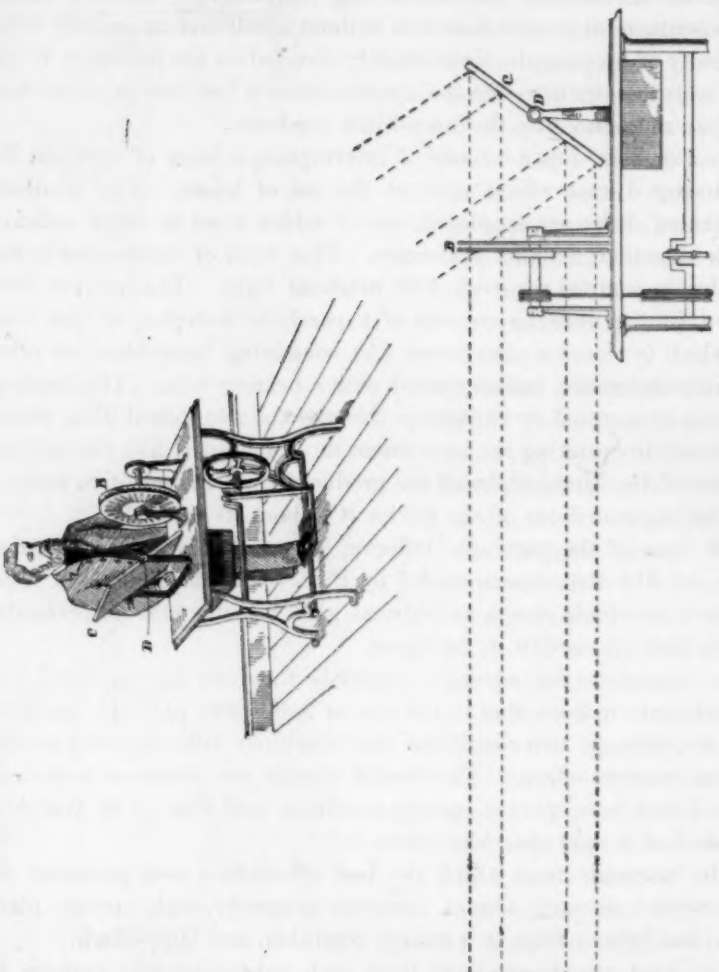


Fig. 3.

Under these circumstances a pulse of air should be expelled, just as we would squeeze out water from a sponge.

The force with which the air is expelled must be greatly increased by the expansion of the air itself, due to contact with the heated particles of lamp-black. When the light is cut off the converse process takes place. The lamp-black particles cool and contract, thus enlarging the air-spaces among them, and the enclosed air also becomes cool. Under these circumstances a partial vacuum should be formed among the particles, and the outside air would then be absorbed, as water is by a sponge when the pressure of the hand is removed.

I imagine that in some such manner as this a wave of condensation is started in the atmosphere each time a beam of sunlight falls upon lamp-black, and a wave of rarefaction is originated when the light is cut off. *We can thus understand how it is that a substance like lamp-black produces intense sonorous vibrations in the surrounding air, while, at the same time, it communicates a very feeble vibration to the diaphragm or solid bed upon which it rests.*

This curious fact was independently observed in England by Mr. Preece, and it led him to question whether, in our experiments with thin diaphragms, the sound heard was due to the vibration of the disk or (as Prof. Hughes had suggested) to the expansion and contraction of the air in contact with the disk confined in the cavity behind the diaphragm. In his paper, read before the Royal Society on the 10th of March, Mr. Preece describes experiments from which he claims to have proved that the effects are wholly due to the vibrations of the confined air, and that the *disks do not vibrate at all.* I shall briefly state my reasons for disagreeing with him in this conclusion:

1. When an intermittent beam of sunlight is focussed upon a sheet of hard rubber or other material a musical tone can be heard, not only by placing the ear immediately behind the part receiving the beam, but by placing it against any portion of the sheet, even though this may be a foot or more from the place acted upon by the light.

2. When the beam is thrown upon the diaphragm of a "Blake Transmitter," a loud musical tone is produced by a telephone connected in the same galvanic circuit with the carbon button (A), Fig. 4. Good effects are also produced when the carbon button (A) forms with the battery (B) a portion of the primary circuit of an induction coil, the telephone (C) being placed in the secondary circuit. In these cases the wooden box and mouth-piece of the transmitter should be

removed, so that no air cavities may be left on either side of the diaphragm.

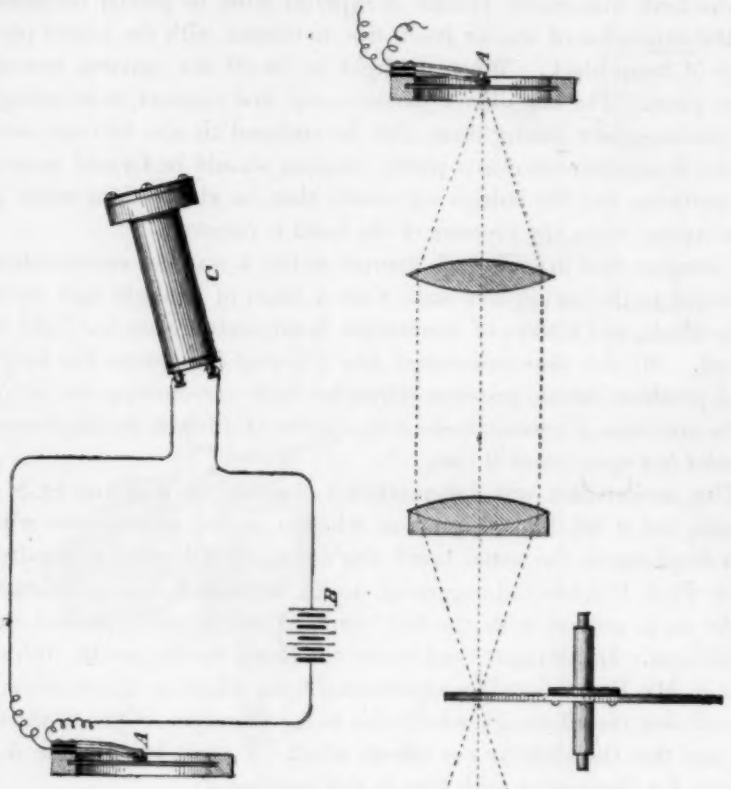


Fig. 4.

It is evident, therefore, that in the case of thin disks a real vibration of the diaphragm is caused by the action of the intermittent beam, independently of any expansion and contraction of the air confined in the cavity behind the diaphragm.

Lord Rayleigh has shown mathematically that a to-and-fro vibration, of sufficient amplitude to produce an audible sound, would result from a periodical communication and abstraction of heat, and he says: "We may conclude, I think, that there is at present no reason for discarding the obvious explanation that the sounds in question are due to the bending of the plates under unequal heating." (*Nature*, xxiii, p. 274.) Mr. Preece, however, seeks to prove that the sonorous effects cannot be explained upon this supposition, but his experimental proof is inadequate to support his conclusion. Mr. Preece expected that if Lord Rayleigh's explanation was correct, the expansion and contraction of a thin strip under the influence of an intermittent beam could be caused to open and close a galvanic circuit so as to produce a musical tone from a telephone in the circuit. But this was an inadequate way to test the point at issue, for Lord Rayleigh has shown (*Proc. Royal Society*, 1877) that an audible sound can be produced by a vibration whose amplitude is *less than a ten-millionth of a centimetre*, and certainly such a vibration as that would not have sufficed to operate a "make-and-break contact" like that used by Mr. Preece. The negative results obtained by him cannot, therefore, be considered conclusive.

The following experiments (devised by Mr. Tainter) have given results decidedly more favorable to the theory of Lord Rayleigh than to that of Mr. Preece.

1. A strip (A) similar to that used in Mr. Preece's experiment was attached firmly to the centre of an iron diaphragm (B), as shown in Fig. 5, and was then pulled taut at right angles to the plane of the diaphragm. When the intermittent beam was focussed upon the strip (A) a clear musical tone could be heard by applying the ear to the hearing-tube (C). *This seemed to indicate a rapid expansion and contraction of the substance under trial.* But a vibration of the diaphragm (B) would also have resulted if the thin strip (A) had acquired a to-and-fro motion, due either to the direct impact of the beam or to the sudden expansion of the air in contact with the strip.

2. To test whether this had been the case, an additional strip (D)

was attached by its central point only to the strip under trial, and was then submitted to the action of the beam, as shown in Fig. 6.

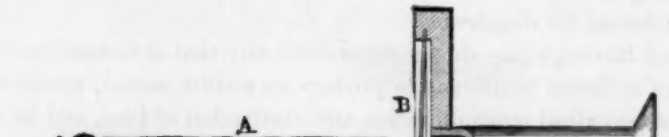


Fig. 5.

It was presumed that if the vibration of the diaphragm (B) had been due to a *pushing force* acting on the strip (A), that the addition of the strip (D) would not interfere with the effect. But if, on the other hand, it had been due to the longitudinal expansion and contraction of the strip (A), the sound would cease, or at least be reduced.

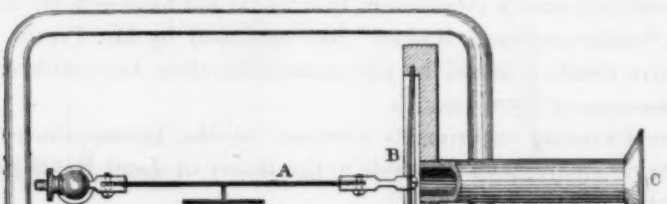


Fig. 6.

The beam of light falling upon strip (D) was now interrupted as before by the rapid rotation of a perforated disk, which was allowed to come gradually to rest. No sound was heard excepting at a certain speed of rotation, when a feeble musical tone became audible. This result is confirmatory of the first.

The audibility of the effect at a particular rate of interruption suggests the explanation that the strip D had a normal rate of vibration of its own.

When the frequency of the interruption of the light corresponded to this, the strip was probably thrown into vibration after the manner of a tuning-fork, in which case a to-and-fro vibration would be propagated down its stem or central support to the strip (A). This indirectly proves the value of the experiment.

The list of solid substances that have been submitted to experiment in my laboratory is too long to be quoted here, and I shall merely say that we have not yet found one solid body that has failed to become sonorous under proper conditions of experiment.*

Experiments with Liquids.

The sounds produced by liquids are much more difficult to observe than those produced by solids. The high absorptive power possessed by most liquids would lead one to expect intense vibrations from the action of intermittent light, but the number of sonorous liquids that have so far been found is extremely limited, and the sounds produced are so feeble as to be heard only by the greatest attention and under the best circumstances of experiment. In the experiments made in my laboratory a very long test-tube was filled with the liquid under examination, and a flexible rubber tube was slipped over the mouth far enough down to prevent the possibility of any light reaching the vapor above the surface. Precautions were also taken to prevent reflection from the bottom of the test-tube. An intermittent beam of sunlight was then focussed upon the liquid in the middle portion of the test-tube by means of a lens of large diameter.

Results.

Clear water,	No sound audible.
Water discolored by ink,	Feeble sound.
Mercury,	No sound heard.
Sulphuric ether,*	Feeble but distinct sound.
Ammonia,	" " "
Ammonio-sulphate of copper,	" " "
Writing ink,	" " "
Indigo in sulphuric acid,	" " "
Chloride of copper,*	" " "

*Carbon and thin microscope glass are mentioned in my Boston paper as non-responsive, and powdered chlorate of potash in the communication to the French Academy (*Comptes Rendus*, vol. xci, p. 595). All these substances have since yielded sounds under more careful conditions of experiment.

The liquids distinguished by an asterisk gave the best sounds.

Acoustic vibrations are always much enfeebled in passing from liquids to gases, and it is probable that a form of experiment may be devised which will yield better results by communicating the vibrations of the liquid to the ear through the medium of a solid rod.

Experiments with Gaseous Matter.

On the 29th of November, 1880, I had the pleasure of showing to Prof. Tyndall in the laboratory of the Royal Institution the experiments described in the letter to Mr. Tainter from which I have quoted above, and Prof. Tyndall at once expressed the opinion that the sounds were due to rapid changes of temperature in the body submitted to the action of the beam. Finding that no experiments had been made at that time to test the sonorous properties of different gases, he suggested filling one test-tube with the vapor of sulphuric ether (a good absorbent of heat), and another with the vapor of bisulphide of carbon (a poor absorbent), and he predicted that if any sound was heard it would be louder in the former case than in the latter. The experiment was immediately made, and the result verified the prediction.

Since the publication of the memoirs of Röntgen* and Tyndall† we have repeated these experiments, and have extended the inquiry to a number of other gaseous bodies, obtaining in every case similar results to those noted in the memoirs referred to.

The vapors of the following substances were found to be highly sonorous in the intermittent beam: Water vapor, coal gas, sulphuric ether, alcohol, ammonia, amylene, ethyl bromide, diethylamene, mercury, iodine and peroxide of nitrogen. The loudest sounds were obtained from iodine and peroxide of nitrogen.

I have now shown that sounds are produced by the direct action of intermittent sunlight from substances in every physical condition (solid, liquid and gaseous), and the probability is therefore very greatly increased that sonorousness under such circumstances will be found to be a universal property of matter.

Upon Substitutes for Selenium in Electrical Receivers.

At the time of my communication to the American Association the loudest effects obtained were produced by the use of selenium, arranged

**Ann. der Phys. und Chem.*, 1881, No. 1, p. 155.

† *Proc. Roy. Soc.*, vol. xxxi, p. 307.

in a cell of suitable construction, and placed in a galvanic circuit with a telephone. Upon allowing an intermittent beam of sunlight to fall upon the selenium a musical tone of great intensity was produced from the telephone connected with it.

But the selenium was very inconstant in its action. It was rarely, if ever, found to be the case that two pieces of selenium (even of the same stick) yielded the same results under identical circumstances of annealing, etc. While in Europe last autumn, Dr. Chichester Bell, of University College, London, suggested to me that this inconstancy of result might be due to chemical impurities in the selenium used. Dr. Bell has since visited my laboratory in Washington, and has made a chemical examination of the various samples of selenium I had collected from different parts of the world. As I understand it to be his intention to publish the results of this analysis very soon, I shall make no further mention of his investigation than to state that he has found sulphur, iron, lead and arsenic in the so-called "selenium," with traces of organic matter; that a quantitative examination has revealed the fact that sulphur constitutes nearly one per cent. of the whole mass, and that when these impurities are eliminated the selenium appears to be more constant in its action and more sensitive to light.

Prof. W. G. Adams* has shown that tellurium, like selenium, has its electrical resistance affected by light, and we have attempted to utilize this substance in place of selenium. The arrangement of cell (shown in Fig. 7) was constructed for this purpose in the early part of 1880; but we failed at that time to obtain any indications of sensitiveness with a reflecting galvanometer. We have since found, however, that when this tellurium spiral is connected in circuit with a galvanic battery and telephone, and exposed to the action of an intermittent beam of sunlight, a distinct musical tone is produced by the telephone. The audible effect is much increased by placing the tellurium cell with the battery in the primary circuit of an induction coil, and placing the telephone in the secondary circuit.

The enormously high resistance of selenium and the extremely low resistance of tellurium suggested the thought that an alloy of these two substances might possess intermediate electrical properties. We have accordingly mixed together selenium and tellurium in different proportions, and, while we do not feel warranted at the present time

* *Proc. Roy. Soc.*, vol. xxiv, p. 163.

in making definite statements concerning the results, I may say that such alloys have proved to be sensitive to the action of light.

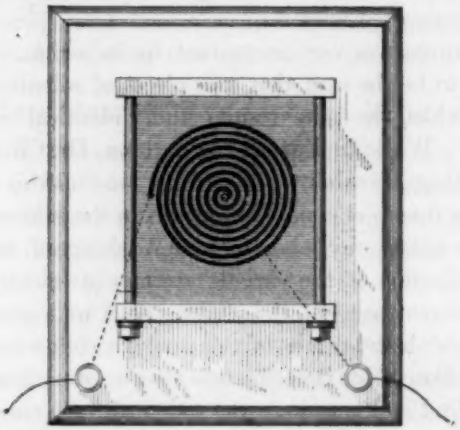


Fig. 7.

It occurred to Mr. Tainter before my return to Washington last January that the very great molecular disturbance produced in lamp-black by the action of intermittent sunlight should produce a corresponding disturbance in an electric current passed through it, in which case lamp-black could be employed in place of selenium in an electrical receiver. This has turned out to be the case, and the importance of the discovery is very great, especially when we consider the expense of such rare substances as selenium and tellurium.

The form of lamp-black cell we have found most effective is shown in Fig. 8. Silver is deposited upon a plate of glass, and a zigzag line is then scratched through the film, as shown, dividing the silver surface into two portions insulated from one another, having the form of two combs with interlocking teeth.

Each comb is attached to a screw-cup, so that the cell can be placed in an electrical circuit when required. The surface is then smoked until a good film of lamp-black is obtained, filling the interstices between the teeth of the silver combs. When the lamp-black cell is connected with a telephone and galvanic battery, and exposed to the influence of an intermittent beam of sunlight, a loud musical tone is produced by the telephone. This result seems to be due rather to the physical condition than to the nature of the conducting material

employed, as metals in a spongy condition produce similar effects. For instance, when an electrical current is passed through spongy platinum while it is exposed to intermittent sunlight, a distinct musical tone is produced by a telephone in the same circuit. In all such cases the effect is increased by the use of an induction coil, and the sensitive cells can be employed for the reproduction of articulate speech as well as for the production of musical sounds.

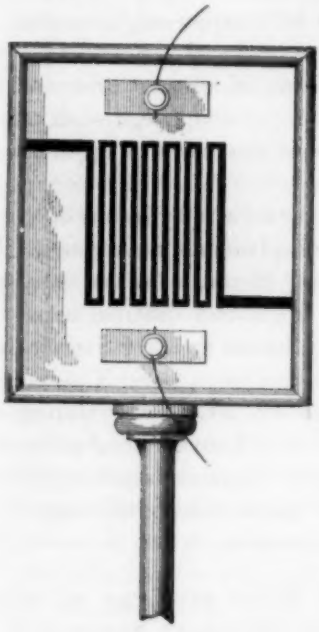


Fig. 8.

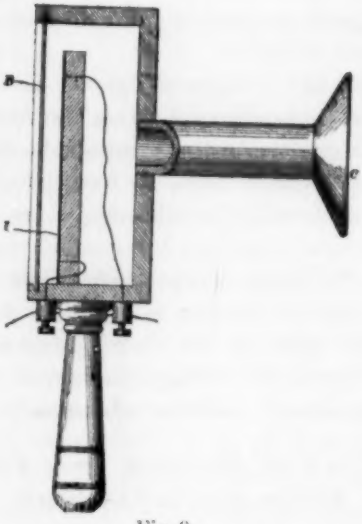


Fig. 9.

We have also found that loud sounds are produced from lamp-black by passing through it an intermittent electrical current, and that it can be used as a telephonic receiver for the reproduction of articulate speech by electrical means.

A convenient mode of arranging a lamp-black cell for experimental purposes is shown in Fig. 9. When an intermittent current is passed through the lamp-black, (*A*), or when an intermittent beam of sunlight falls upon it through the glass plate, *B*, a loud musical tone can be heard by applying the ear to the hearing-tube, *C*. When the light and the electrical current act simultaneously, two musical tones

are perceived, which produce beats when nearly of the same pitch. By proper arrangements a complete interference of sound can undoubtedly be produced.

Upon the Measurement of the Sonorous Effects Produced by Different Substances.

We have observed that different substances produce sounds of very different intensities under similar circumstances of experiment, and it has appeared to us that very valuable information might be obtained if we could measure the audible effects produced. For this purpose we have constructed several different forms of apparatus for studying the effects, but as our researches are not yet complete, I shall confine myself to a simple description of some of the forms of apparatus we have devised.

When a beam of light is brought to a focus by means of a lens, the beam diverging from the focal point becomes weaker as the distance increases in a calculable degree. Hence, if we can determine the distances from the focal point at which two different substances emit sounds of equal intensity, we can calculate their relative sonorous powers.

Preliminary experiments were made by Mr. Tainter during my absence in Europe to ascertain the distance from the focal point of a lens at which the sound produced by a substance became inaudible. A few of the results obtained will show the enormous differences existing between different substances in this respect.

Table of Distances from Focal Point of Lens at which Sounds become Inaudible with Different Substances.

Zinc diaphragm (polished),		1·51 m.
Hard rubber diaphragm,		1·90 "
Tin-foil	"	2·00 "
Telephone	" (Japanned iron),	2·15 "
Zinc	" (unpolished),	2·15 "
White silk	(In receiver shown in Fig. 1),	3·10 "
White worsted	" " "	4·01 "
Yellow worsted	" " "	4·06 "
Yellow silk	" " "	4·13 "
White cotton-wool	" " "	4·38 "
Green silk	" " "	4·52 "

Blue worsted	(In receiver shown in Fig. 1),	4·69 m.
Purple silk	" " "	4·82 "
Brown silk	" " "	5·02 "
Black silk	" " "	5·21 "
Red silk	" " "	5·24 "
Black worsted	" " "	6·50 "
Lamp-black. In receiver the limit of audibility could not be determined on account of want of space. Sound perfectly audible at a distance of		10·00 "

Mr. Tainter was convinced from these experiments that this field of research promised valuable results, and he at once devised an apparatus for studying the effects, which he described to me upon my return from Europe. The apparatus has since been constructed, and I take great pleasure in showing it to you to-day.

(1.) A beam of light is received by two similar lenses (A B, Fig. 10), which bring the light to a focus on either side of the interrupting disk (C). The two substances, whose sonorous powers are to be compared, are placed in the receiving vessels (D E) (so arranged as to expose equal surfaces to the action of the beam) which communicate by flexible tubes (F G) of equal length with the common hearing-tube (H). The receivers (D E) are placed upon slides, which can be moved along the graduated supports (I K). The beams of light passing through the interrupting disk (C) are alternately cut off by the swinging of a pendulum, (L). Thus a musical tone is produced alternately from the substance in D and from that in E. One of the receivers is kept at a constant point upon its scale, and the other receiver is moved towards or from the focus of its beam until the ear decides that the sounds produced from D and E are of equal intensity. The relative positions of the receivers are then noted.

(2.) Another method of investigation is based upon the production of an interference of sound, and the apparatus employed is shown in Fig. 11. The interrupter consists of a tuning-fork, (A), which is kept in continuous vibration by means of an electro-magnet (B). A powerful beam of light is brought to a focus between the prongs of the tuning-fork (A), and the passage of the beam is more or less obstructed by the vibration of the opaque screens (C D) carried by the prongs of the fork. As the tuning-fork (A) produces a sound by its own vibration, it is placed at a sufficient distance away to be inaudible through the air, and a system of lenses is employed for the purpose of bringing

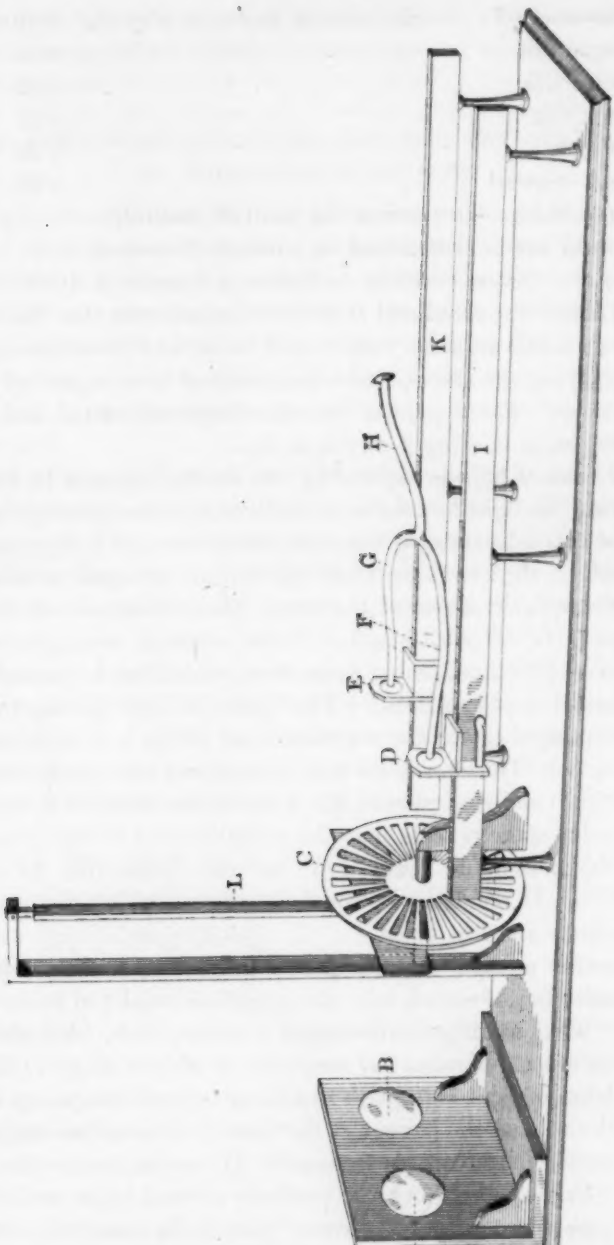


Fig. 10.

the undulating beam of light to the receiving lens (E) with as little loss as possible. The two receivers (F G) are attached to slides (H I), which move upon opposite sides of the axis of the beam, and the receivers are connected by flexible tubes of unequal length (K L), communicating with the common hearing-tube (M). The length of the tube (K) is such that the sonorous vibrations from the receivers (F G) reach the common hearing-tube, (M), in opposite phases. Under these circumstances silence is produced when the vibrations in the receivers (F G) are of equal intensity. When the intensities are unequal, a residual effect is perceived. In operating the instrument the position of the receiver (G) remains constant, and the receiver (F) is moved to or from the focus of the beam until complete silence is produced. The relative positions of the two receivers are then noted.

(3.) Another mode is as follows: The loudness of a musical tone produced by the action of light is compared with the loudness of a tone of similar pitch produced by electrical means. A rheostat introduced into the circuit enables us to measure the amount of resistance required to render the electrical sound equal in intensity to the other.

(4.) If the tuning-fork (A) in Fig. 11 is thrown into vibration by an undulatory instead of an intermittent current passed through the electro-magnet (B), it is probable that a musical tone, electrically produced in the receiver (F) by the action of the same current, would be found capable of extinguishing the effect produced in the receiver (G) by the action of the undulatory beam of light, in which case it should be possible to establish an acoustic balance between the effects produced by light and electricity by introducing sufficient resistance into the electric circuit.

Upon the Nature of the Rays that Produce Sonorous Effects in Different Substances.

In my paper read before the American Association last August and in the present paper I have used the word "light" in its usual rather than its scientific sense, and I have not hitherto attempted to discriminate the effects produced by the different constituents of ordinary light, the thermal, luminous and actinic rays. I find, however, that the adoption of the word "photophone" by Mr. Tainter and myself has led to the assumption that we believed the audible effects discovered by us to be due entirely to the action of luminous rays. The mean-

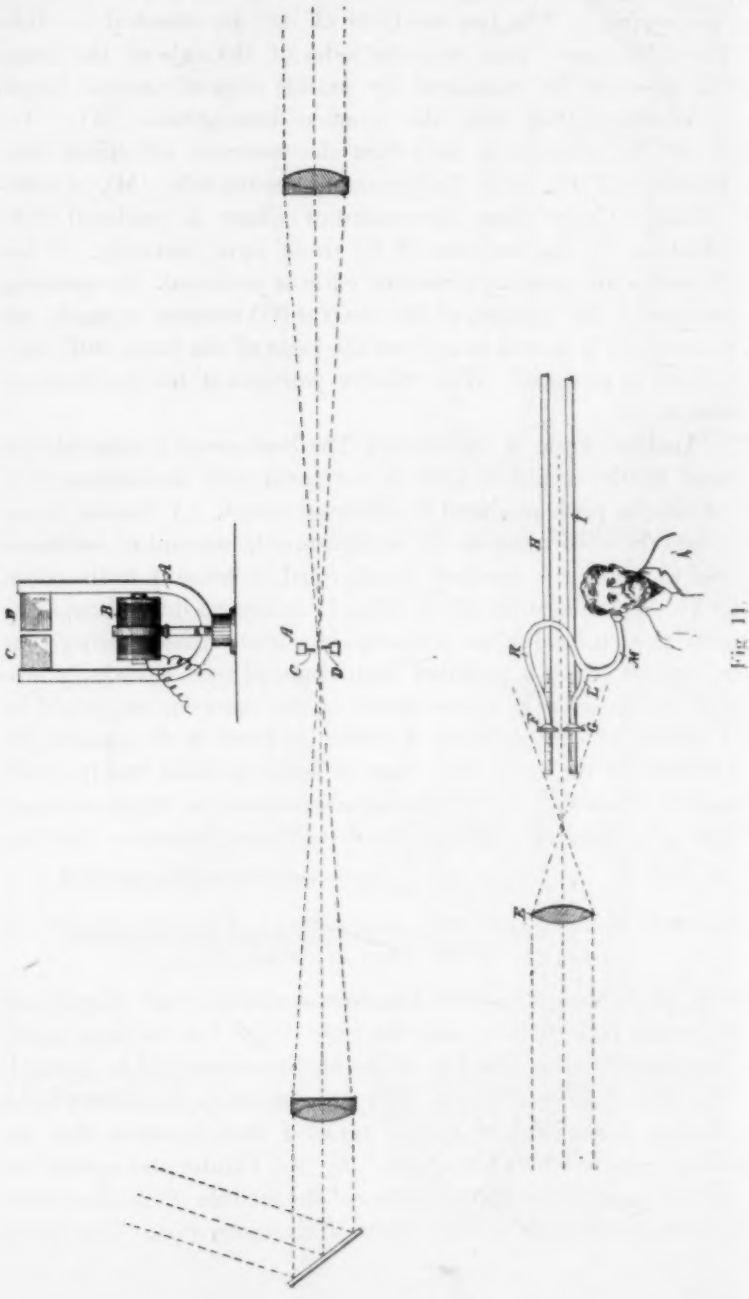


Fig. 11.

ing we have uniformly attached to the words "photophone" and "light" will be obvious from the following passage, quoted from my Boston paper:

"Although effects are produced as above shown by forms of radiant energy, which are invisible, we have named the apparatus for the production and reproduction of sound in this way the 'photophone' *because an ordinary beam of light contains the rays which are operative.*"

To avoid in future any misunderstandings upon this point we have decided to adopt the term "*radiophone*," proposed by M. Mercadier, as a general term signifying an apparatus for the production of sound by any form of radiant energy, limiting the words *thermophone*, *photophone* and *actinophone* to apparatus for the production of sound by thermal, luminous or actinic rays, respectively.

M. Mercadier, in the course of his researches in radiophony, passed an intermittent beam from an electric lamp through a prism, and then examined the audible effects produced in different parts of the spectrum. (*Comptes Rendus*, Dec. 6th, 1880.) We have repeated this experiment, using the sun as our source of radiation, and have obtained results somewhat different from those noted by M. Mercadier. A beam of sunlight was reflected from a heliostat (A, Fig. 12) through an achromatic lens (B), so as to form an image of the sun upon the slit (C). The beam then passed through another

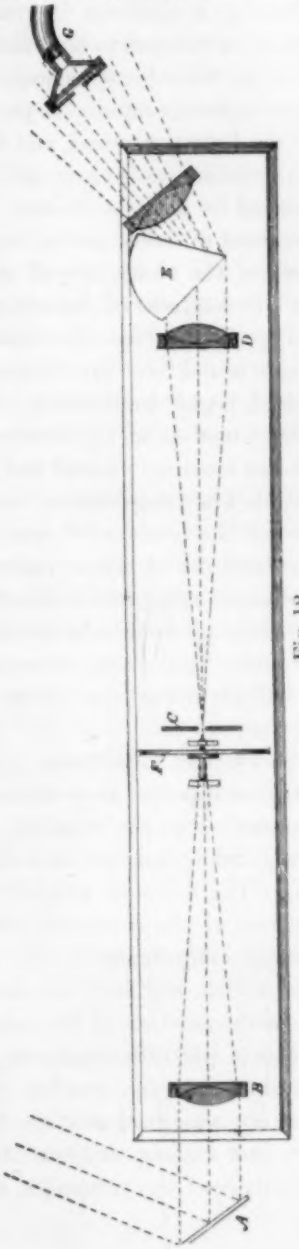


Fig. 12.

achromatic lens (D) and through a bisulphide of carbon prism (E), forming a spectrum of great intensity, which, when focused upon a screen, was found to be sufficiently pure to show the principal absorption lines of the solar spectrum. The disk-interrupter (F) was then turned with sufficient rapidity to produce from five to six hundred interruptions of the light per second, and the spectrum was explored with the receiver (G), which was so arranged that the lamp-black surface exposed was limited by a slit, as shown. Under these circumstances sounds were obtained in every part of the visible spectrum, excepting the extreme half of the violet, as well as in the ultra-red. A continuous increase in the loudness of the sound was observed upon moving the receiver (G) gradually from the violet into the ultra-red. The point of maximum sound lay very far out in the ultra-red. Beyond this point the sound began to decrease, and then stopped so suddenly that a very slight motion of the receiver (G) made all the difference between almost maximum sound and complete silence.

(2.) The lamp-blacked wire gauze was then removed and the interior of the receiver (G) was filled with red worsted. Upon exploring the spectrum as before, entirely different results were obtained. The maximum effect was produced in the green at that part where the red worsted appeared to be black. On either side of this point the sound gradually died away, becoming inaudible on the one side in the middle of the indigo, and on the other at a short distance outside the edge of the red.

(3.) Upon substituting green silk for red worsted, the limits of audition appeared to be the middle of the blue and a point a short distance out in the ultra-red. Maximum in the red.

(4.) Some hard-rubber shavings were now placed in the receiver (G). The limits of audibility appeared to be on the one hand the junction of the green and blue, and on the other the outside edge of the red. Maximum in the yellow. Mr. Tainter thought he could hear a little way into the ultra-red, and to his ear the maximum was about the junction of the red and orange.

(5.) A test-tube containing the vapor of sulphuric ether was then substituted for the receiver (G). Commencing at the violet end, the test-tube was gradually moved down the spectrum and out into the ultra-red without audible effect, but when a certain point far out in the ultra-red was reached a distinct musical tone suddenly made its

appearance, which disappeared as suddenly on moving the test-tube a very little further on.

(6.) Upon exploring the spectrum with a test-tube containing the vapor of iodine, the limits of audibility appeared to be the middle of the red and the junction of the blue and indigo. Maximum in the green.

(7.) A test-tube containing peroxide of nitrogen was substituted for that containing iodine. Distinct sounds were obtained in all parts of the visible spectrum, but no sounds were observed in the ultra-red.

The maximum effect seemed to me to be in the blue. The sounds were well marked in all parts of the violet, and I even fancied that the audible effect extended a little way into the ultra-violet, but of this I cannot be certain. Upon examining the absorption spectrum of peroxide of nitrogen it was at once observed that the maximum sound was produced in that part of the spectrum where the greatest number of absorption lines made their appearance.

(8.) The spectrum was now explored by a selenium cell, and the audible effects were observed by means of a telephone in the same galvanic circuit with the cell. The maximum effect was produced in the red. The audible effect extended a little way into the ultra-red on the one hand, and up as high as the middle of the violet on the other.

Although the experiments so far made can only be considered as preliminary to others of a more refined nature, I think we are warranted in concluding that *the nature of the rays that produce sonorous effects in different substances depends upon the nature of the substances that are exposed to the beam, and that the sounds are in every case due to those rays of the spectrum that are absorbed by the body.*

The Spectrophone.

Our experiments upon the range of audibility of different substances in the spectrum have led us to the construction of a new instrument for use in spectrum analysis, which was described and exhibited to the Philosophical Society of Washington.* The eye-piece of a spectroscope is removed, and sensitive substances are placed in the focal point of the instrument behind an opaque diaphragm containing a slit. These substances are put in communication with the

* Proc. of Phil. Soc. of Washington, April 16, 1881.

ear by means of a hearing-tube, and thus the instrument is converted into a veritable "spectrophone," like that shown in Fig. 13.

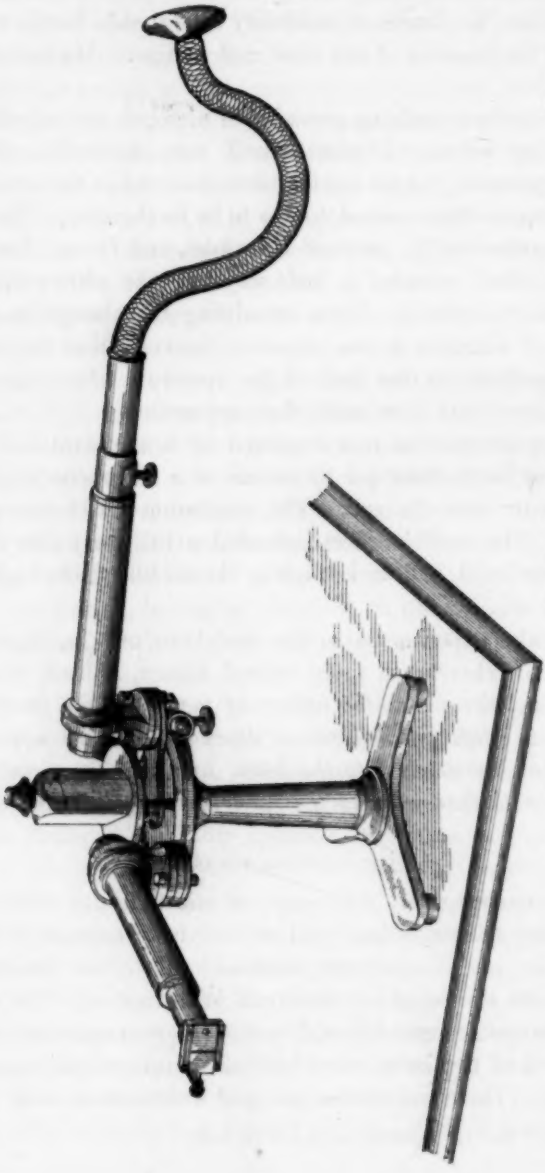


Fig. 13.

Suppose we smoke the interior of our spectrophonic receiver, and fill the cavity with peroxide of nitrogen gas. We have then a combination that gives us good sounds in all parts of the spectrum (visible and invisible), except the ultra-violet. Now pass a rapidly-interrupted beam of light through some substance whose absorption spectrum is to be investigated, and bands of sound and silence are observed upon exploring the spectrum, the silent positions corresponding to the absorption bands. Of course, the ear cannot for one moment compete with the eye in the examination of the visible part of the spectrum: but in the invisible part beyond the red, where the eye is useless, the ear is invaluable. In working in this region of the spectrum, lamp-black alone may be used in the spectrophonic receiver. Indeed, the sounds produced by this substance in the ultra-red are so well marked as to constitute our instrument a most reliable and convenient substitute for the thermo-pile. A few experiments that have been made may be interesting.

(1.) The interrupted beam was filtered through a saturated solution of alum. Result: The range of audibility in the ultra-red was slightly reduced by the absorption of a narrow band of the rays of lowest refrangibility. The sounds in the visible part of the spectrum seemed to be unaffected.

(2.) A thin sheet of hard rubber was interposed in the path of the beam. Result: Well-marked sounds in every part of the ultra-red. No sounds in the visible part of the spectrum, excepting the extreme half of the red.

These experiments reveal the cause of the curious fact alluded to in my paper read before the American Association last August—that sounds were heard from selenium when the beam was filtered through both hard rubber and alum at the same time. (See diagram of results in Fig. 14.)

(3.) A solution of ammonia-sulphate of copper was tried. Result: When placed in the path of the beam the spectrum disappeared, with the exception of the blue and violet end. To the eye the spectrum was thus reduced to a single broad band of blue-violet light. To the ear, however, the spectrum revealed itself as two bands of sound with a broad space of silence between. The invisible rays transmitted constituted a narrow band just outside the red.

I think I have said enough to convince you of the value of this new method of examination, but I do not wish you to understand

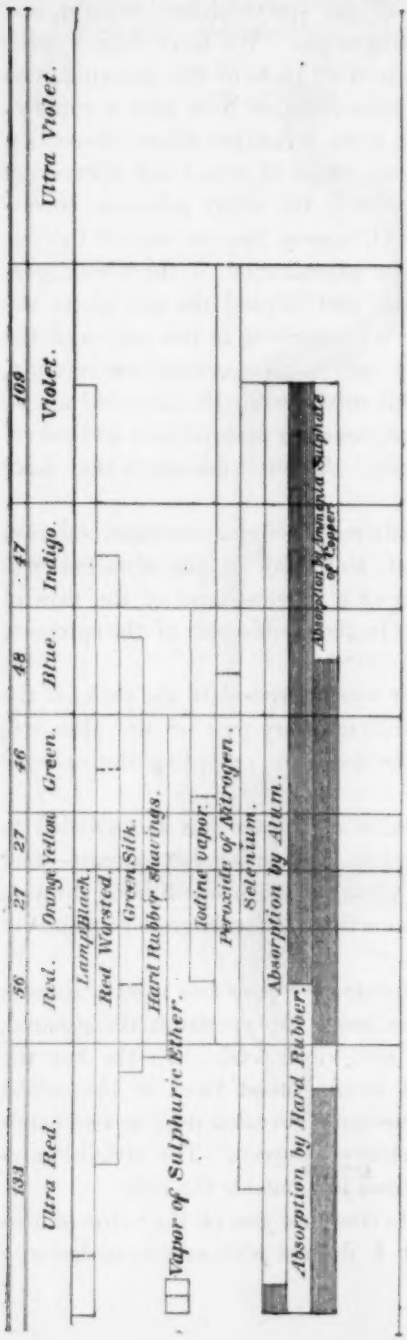


Fig. 14.

that we look upon our results as by any means complete. It is often more interesting to observe the first totterings of a child than to watch the firm tread of a full-grown man, and I feel that *our* first footsteps in this new field of science may have more of interest to you than the fuller results of mature research. This must be my excuse for having dwelt so long upon the details of incomplete experiments.

I recognize the fact that the spectrophone must ever remain a mere adjunct to the spectroscope, but I anticipate that it has a wide and independent field of usefulness in the investigation of absorption spectra in the ultra-red.

Tunnel of the English Channel. — The preliminary works of the tunnel which is to unite England and France have presented very satisfactory results. The engineers have sunk a shaft to the stratum in which they propose to bore the tunnel, and they are now engaged upon a new shaft for receiving all the boring apparatus. They expect to bore at least 2½ miles within 18 months and to finish the work in 10 years.—*L'Ingen. Univ.* C.

An Account of the Experiments made in Mulhouse, Germany, by a Committee of the Industrial Society of that City, on a Corliss Steam Engine, to Determine its Economic Performance with and without Steam-Jacketing.

By Chief Engineer Isherwood, U. S. Navy.

(Continued from page 371.)

Results of the Experiments.

In all the experiments except *H*, *I*, *J* and *K*, the cut-off was fixed, so that the measure of expansion with which the steam was used did not vary during each experiment. In experiments *H*, *I*, *J* and *K*, the cut-off was variable by the action of the governor, but the uniformity of the load and the steadiness of the steam pressure restricted the point of cutting off within very narrow limits.

The economy of the performance in the different experiments may be compared for the total horse-power and for the net horse-power developed by the engine, the units of heat consumed per hour per horse-power being taken as the measure of the economy. The total horse-power represents the entire dynamic effect of the steam, including overcoming the external load and the internal resistance of the back pressure against the piston and all the friction resistances. The net horse-power represents that portion of the entire dynamic effect of the steam which is expended in overcoming the external load and the friction of that load; it is exclusive of the dynamic effect expended in overcoming the internal resistance of the back pressure against the piston, and of the friction of the unloaded engine. The net horse-power is the only portion of the dynamic effect of the steam which is commercially valuable, and its greater or less cost is the only economic problem in this relation to the user of steam power.

Of the economy due to the different measures of expansion with which the steam was used. In the case of experiments *A*, *B* and *C*, where there was no steam present in the cylinder jackets or piston, the steam was expanded 12·3978 times in experiment *A*, and 7·9033 times in experiments *B* and *C*. Now as experiment *C* was a repetition of

experiment *B*, the mean of the economic results of the two may be taken as the cost of the power in units of heat consumed per hour. That mean for the total horse-power is $\left(\frac{26143{\cdot}4461+25621{\cdot}4174}{2}=\right)$ 25882·4317 units. The cost of the total horse-power in experiment *A* was 26731·8267 units of heat consumed per hour; hence, for the total horse-power under the conditions of these experiments, expanding the steam 12·3978 times, gave $\left(\frac{26731{\cdot}8267-25882{\cdot}4317\times100}{25882{\cdot}4317}=\right)$ 3·2817 per centum less economy than expanding it 7·9033 times.

Making the same comparison for the net horse-power, we have for its cost, as the mean of the experiments *B* and *C*,

$$\left(\frac{32440{\cdot}2587+31735{\cdot}4286}{2}=\right)$$

32087·8436 units of heat consumed per hour, the steam being expanded 7·9033 times. In experiment *A*, in which the steam was expanded 12·3978 times, the cost of the net horse-power was 37285·6168 units of heat consumed per hour; hence, for the net horse-power under the conditions of these experiments, expanding the steam 12·3978 times gave $\left(\frac{37285{\cdot}6168-32087{\cdot}8436\times100}{32087{\cdot}8436}=\right)$ 16·1986 per centum less economy than expanding it 7·9033 times.

In the case of experiments *E* and *F*, where steam was present in the cylinder jackets, but not in the piston, the steam was expanded 10·8259 times in experiment *E*, and 5·7037 times in experiment *F*. The cost of the total horse-power in experiment *E* was 19452·7617 units of heat consumed per hour, and in experiment *F* 20230·7613 units; hence, for the total horse-power under the conditions of these experiments, expanding the steam 10·8259 times gave

$$\left(\frac{20230{\cdot}7613-19452{\cdot}7617\times100}{20230{\cdot}7613}=\right)$$

3.8456 per centum more economy than expanding it 5·7037 times.

Making the same comparison for the net horse-power, we have for its cost in experiment *E* 25542·3868 units of heat consumed per hour, and in experiment *F* 24223·0957 units; hence, for the net horse-power under the conditions of these experiments, expanding the steam 10·8259 times gave $\left(\frac{25542{\cdot}3868-24223{\cdot}0957\times100}{24223{\cdot}0957}=\right)$ 5·4464 per centum less economy than expanding it 5·7037 times.

In the case of experiments *G*, *H*, *I*, *J*, *K* and *L*, where steam was present in the cylinder jackets and in the piston, the steam was expanded a different number of times in each experiment, varying from 5·7037 to 10·8259 times. The following table shows the relative costs of the total horse-power and of the net horse-power for these different measures of expansion in units of heat consumed per hour, assuming for unity the cost of the horse-power with the steam expanded 5·7037 times.

Designation of experiment.	Number of times the steam was expanded.	Relative costs of the horse-power in units of heat consumed per hour.	
		Total horse-power.	Net horse-power.
L	5·7037	1·0000	1·0000
K	5·8670	0·9639	0·9649
J	6·4182	0·9712	0·9758
I	6·8471	0·9692	0·9797
H	7·9033	0·9384	0·9719
G	10·8259	0·9199	0·9984

The general results as regards the different measures of expansion with which the steam was used are: 1st. That with saturated steam, steam jacketing allows a greater gain to be realized with large measures of expansion than can be had without steam jacketing. In other words, expansion can beneficially be carried farther with steam jacketing than without. 2d. That with steam jacketing under the conditions of these experiments the total horse-power is obtained with slightly increasing economy as the measure of expansion increases; but that, on the contrary, a small economic loss is experienced as regards the net horse-power with each increase of the measure of expansion beyond about 5¾ times.

Without steam jacketing and using saturated steam, an economic loss was sustained for both the total and the net horse-power, small for the first and large for the last, when the measure of expansion was increased from 7·9033 to 12·3978 times.

In connection with steam jacketing and different measures of expansion, it will be observed that the per centum of the steam evap-

orated in the boiler, condensed in the steam jackets, increased regularly as the measure of expansion increased, rising from 4·6050 per centum when the steam was expanded 5·7037 times (experiment *L*) to 6·4641 when the steam was expanded 10·8259 times (experiment *G*). This was as it should be, the greater cylinder refrigeration accompanying the greater measure of expansion, must necessarily draw from the steam jackets a greater proportion of heat. The fact that the jackets furnish a reservoir of heat for counteracting the greater cylinder refrigeration due to the greater measures of expansion, allows these greater measures to be more economically beneficial with steam jacketing than without it, as shown by the experiment.

The results of these experiments show that, as regards economy of fuel, there is no gain in a variable cut-off actuated by the governor of the engine between the limits of expansion employed. The variable cut-off in these cases was only useful for the graduation of the power which it probably accomplished somewhat more promptly than could have been effected by connecting the governor with a throttle valve.

It is necessary to here caution the reader that the condition of constant piston speed in the same cylinder, under which these experiments were made, is exceptionally favorable for obtaining relatively the highest economic results for the greater measures of expansion. This uniformity of piston speed was maintained by the action of the spare duplicate engine connected on the same shaft and supplying the complement of power for equal speed, let the power of the experimental engine vary as it might owing to the variations in the measures of expansion with which the steam of the same boiler pressure was used.

In regular practice, with the same cylinder, a constant boiler pressure, and a constant load, the piston speed decreases as the measure of expansion increases, because the piston pressure becomes correspondingly less and less. The weight of steam condensed in the cylinder per hour in addition to the condensation due to the development of the total power, and caused by the variations in the temperature of the interior metallic surfaces of the cylinder during a stroke of the piston, being nearly constant in these cases, while the weight of steam evaporated per hour in the boiler is smaller and smaller as the power becomes smaller and smaller, the steam condensed in the cylinder becomes necessarily a larger proportion of the steam evaporated in the boiler, and the economy of the performance correspondingly decreases

with every increase in the measure of expansion. Had the experiments been made under these unavoidable conditions of regular practice, the economic results of the greater measures of expansion would have been much less than they were. There would have probably been some loss in economic effect for the total horse-power, and certainly a marked loss for the net horse-power in all the cases where the measure of expansion exceeded the lowest employed, namely: 5·7037 times. If we seek to preserve the economic effect of the higher measures of expansion when a constant piston speed is maintained, by preserving that speed in a cylinder of corresponding size to give the same development of power with constant load and the same boiler pressure, there still results the larger condensation of steam per hour in the larger cylinder due to the greater extent of its interior surfaces.

Of the economy due to steam of the boiler pressure in the cylinder jackets and piston. To ascertain the economic gain due to steam jacketing the cylinder and piston with steam of the boiler pressure, the cost of the total horse-power must be compared in the case of the jacketing with the similar cost in the case of no jacketing, taking care that in both cases the initial steam pressure on the piston and the mean back pressure against it, the measure of expansion with which the steam was used, the speed of the piston, and the total horse-power developed by the engine, are about the same.

For the determination without steam in the cylinder jackets and piston, we have the mean of experiments *B* and *C*, giving for the initial pressure on the piston 71·0445 pounds per square inch above zero, for the back pressure against the piston 3·1170 pounds per square inch above zero, for the measure of expansion with which the steam was used 7·9033 times, for the speed of the piston 49·2003 double strokes per minute, and for the total horse-power developed 144·0238.

For the determination with steam in the cylinder jackets and piston, we have the results of the comparable experiment *H* in which the initial pressure on the piston was 71·2090 pounds per square inch above zero, the back pressure against the piston 3·1599 pounds per square inch above zero, the measure of expansion 7·9033 times, the speed of the piston 51·0981 double strokes per minute, and the total horse-power 151·5674.

The mean of experiments *B* and *C* gave for the cost of the total horse-power 25882·4317 units of heat consumed per hour. Experi-

ment H gave for the cost of the total horse-power 19381·3170 units of heat consumed per hour; consequently steam jacketing the cylinder and piston produced an economic gain of

$$\left(\frac{25882{\cdot}4317 - 19381{\cdot}3170 \times 100}{25882{\cdot}4317} = \right)$$

25·1179 per centum.

It is to be regretted that the experiments without steam jacketing were not more numerous and made with more varied measures of expansion, so that a greater number of comparisons might have been obtained with the experiments in which steam jacketing was employed. The want of more comparable experiments may be supplied, but not with strict accuracy, by comparing the mean of the results given by experiments A, B and C, in which there was no steam in the cylinder jackets and piston, with the mean of the results given by experiments G and H, in which steam of boiler pressure was in the cylinder jackets and piston, the average measure of expansion for experiments A, B and C being almost exactly the average for experiments G and H.

The mean results of experiments A, B and C are: initial pressure on the piston 71·3507 pounds per square inch above zero, back pressure against the piston 3·0733 pounds per square inch above zero, measure of expansion 9·4015 times, speed of piston 49·4423 double strokes per minute, total horse-power developed by the engine 128·4708, and units of heat consumed per hour per total horse-power 26165·5634.

The mean results of experiments G and H are: initial pressure on the piston 71·8300 pounds per square inch above zero, back pressure against the piston 3·0588 pounds per square inch above zero, measure of expansion 9·3646 times, speed of piston 50·7483 double strokes per minute, total horse-power developed by the engine 135·4667, and units of heat consumed per hour per total horse-power 19190·6949.

From the above data, steam jacketing the cylinder and piston produced an economic gain of $\left(\frac{26165{\cdot}5634 - 19190{\cdot}6949 \times 100}{26165{\cdot}5634} = \right)$ 26·6566 per centum.

Inasmuch as during the previous experiments, those made with steam of boiler pressure in the cylinder jackets and piston had the advantage of a slightly greater piston speed over those made without steam in the cylinder jackets and piston, the economic gain due to the former over the latter may be taken at 25 per centum.

In experiments *G* and *H* there were drained from the cylinder jackets alone $\left(\frac{5{\cdot}1224+4{\cdot}7990}{2}=\right)$ 4·9607 per centum of the water vaporized in the boiler; and from the piston alone $\left(\frac{1{\cdot}3417+1{\cdot}2254}{2}=\right)$ 1·2835 per centum of the water vaporized in the boiler, making a total of (4·9607+1·2835=) 6·2442 per centum, of which roundly one-fifth was contributed by the piston and four-fifths by the cylinder jackets, being almost exactly in the proportion of the steam jacketed surfaces of the piston to the steam jacketed surfaces of the cylinder, showing that per unit of surface the jacketing of the piston gave about the same condensation as the jacketing of the cylinder.

If, from the weight of feed water pumped into the boiler in experiment *H* there be deducted the weight of water of condensation drained from the cylinder jackets and piston, there will remain 2448·4284 pounds of water which entered the cylinder per hour in the form of steam containing 2760609·1421 units of heat, so that the total horse-power in that experiment cost 18213·7395 units of heat exclusive of the units in the steam supplying the cylinder jackets and piston.

Comparing this result with the mean cost of the total horse-power in units of heat consumed per hour during experiments *B* and *C* (25882·4317 units), in which there was no steam in the cylinder jackets and piston, there is found an economic gain of

$$\left(\frac{25882{\cdot}4317-18213{\cdot}7395\times 100}{25882{\cdot}4317}=\right)$$

29·6290 per centum for the steam jacketing, showing that the condensation in the steam cylinder during experiments *B* and *C* exceeded that in experiment *H* by at least 29·6290 per centum of the feed water pumped into the boiler. The economy effected by the steam jacketing resulted entirely from this great lessening of the enormous cylinder condensation which always takes place in small cylinders using saturated steam with large measures of expansion.

In experiment *H* a condensation in the steam jackets of 6·0244 per centum of the steam evaporated in the boiler prevented a condensation in the cylinder of 29·6290 per centum of the water evaporated in the boiler. This condensation in the jackets included not only the heat imparted to the interior surfaces of the cylinder, but also the heat lost by radiation from the exterior surfaces of the cylinder jackets. As

these latter, however, were thoroughly protected by a covering of non-conducting materials, the loss from that cause must have been quite insignificant; but, whatever it was, a part of it should be deducted from the 6·0244 per centum, because, had there been no steam jackets, there would have been some, but less, radiation from the exterior surfaces of the cylinder; less, because the exterior surfaces of the cylinder and the steam pressure within it are less than for the jackets.

Again, under the conditions of ordinary practice, the steam jacketing would have given a slightly greater economy than in these experiments, because, in that case, the water of condensation from the jackets is delivered directly into the boiler with nearly the temperature of the steam in the latter having lost therein only its latent heat; while, in the case of the experiments, this water of condensation was cooled down to about the feed water temperature by being drained into measuring tanks before returning to the boiler. In experiment *H*, every pound of the water of condensation drained from the jackets thus lost about 231 units of heat; had this been saved, as it might be in regular practice, the economic gain by the steam jacketing would have been increased 1·23 per centum, so that the true gain in fuel in regular practice due to the presence of steam in the cylinder jackets and piston would have been about 26·5 per centum.

It must not be supposed that this gain is absolute and the same for all steam engines; on the contrary, it is relative to the type of engine, to the proportions of the cylinder, to the dimensions of the cylinder, to the initial pressure on the piston and the back pressure against it, to the measure of expansion with which the steam is used, to the degree of superheating the steam may possess on entering the cylinder, to the proportion of water entrained by the steam, and to the speed of piston. In brief, the gain due to steam jacketing is affected by all the causes which affect the condensation of steam in the cylinder other than the condensation due to the transmutation of the heat, thus set free, into the total horse-power developed by the expanding steam alone.

Different types of engine require, for the same cylinder, different space in the clearance and in the steam passage; they also allow a different proportion of the exterior of the cylinder to be utilized for jackets. Thus, with the same dimensions of cylinder, the area of steam jacketing may be less, and the area of the internal surface of the cylinder, including surfaces of clearance and steam passage, more with

one type than with another, in which case steam jacketing would be less economical than in the reverse case. Other things equal, the proportions of cylinder which diminish the gain due to steam jacketing are those which enclose a given space with the least superficies; for then a given mass of steam is exposed to the least condensing surface. The larger the dimensions of the cylinder, other things equal, the less the gain by steam jacketing, because the mass of steam increases as the cube of the dimensions, while its enclosing or condensing surface increases as the square only. The less the difference, other things equal, between the initial pressure on the piston and the back pressure against it, the less will be the gain by steam jacketing, as this difference is one of the causes of cylinder condensation. The greater the degree of superheating possessed by the steam, other things equal, the less will be the gain due to steam jacketing, because there will be less cylinder condensation for the jacket to act on. With a degree of superheating sufficient to prevent condensation, steam jacketing would be nugatory. The greater the proportion of water entrained by the steam, the greater will be the economic gain by steam jacketing, for the presence of water in the cylinder greatly increases the cylinder condensation, as it has to be boiled off during the expansion and the exhaust strokes largely by heat taken from the metal of the cylinder, and this deficit must be restored by the entering steam which to that extent undergoes condensation. The greater the speed of the piston, other things equal, the less will be the gain by steam jacketing; for, although the weight of steam condensed per hour, in the same cylinder, under this condition, may be nearly the same with all speeds of piston within practical limits, yet as the mass of steam passing through the cylinder in a given time will be in direct proportion to the piston speed, the cylinder condensation will be correspondingly reduced in proportion to the boiler evaporation; for example, if, with a given speed of piston, the condensation was 20 per centum of the steam evaporated in the boiler, then, with the piston speed doubled, this condensation would fall to 10 per centum, provided always that the metal of the cylinder transmitted the jacket temperature to the interior surfaces of the cylinder as rapidly as the steam came upon them. If this transmission was slower, then the reduction in the per centum of the condensation would not be so great.

Of the economy due to steam of the boiler pressure in the cylinder jackets alone — not in the piston. We have already ascertained the

economic gain due to the presence of steam of boiler pressure in the cylinder jackets and in the piston; there remains to determine this gain for the piston alone. The committee should have made a direct experiment for the purpose of ascertaining the economic efficiency of the steam jacketed surfaces of the piston, by leaving the steam out of the cylinder jackets and experimenting with it in the piston alone. Instead of this, they deducted the economic results when using steam in the cylinder jackets alone from those obtained when using it in the cylinder jackets and piston combined. This, indeed, showed how much, in the particular experimental case, the extension of the steam jacketing to the piston affected the economic gain, but it could not show the efficiency of the jacketed surfaces of the piston, *per se*. As an illustration of the fact at issue, suppose that the cylinder jackets alone were able to prevent or nearly prevent any condensation in the cylinder, then it is obvious that the addition of the jacketed surfaces of the piston could have produced no additional effect; but, if the cylinder jackets still left a considerable cylinder condensation, then the additional jacketed surfaces of the piston would have proved very efficient.

The strictly comparable experiments for determining the efficiency of the steam jacketed piston in combination with the steam jackets of the cylinder are E with G, and F with L. In E and F, only the cylinder jackets were in use; in G and L they were in use in combination with steam in the piston.

In experiment E the total horse-power cost 19452·7617 units of heat per hour; in experiment G it cost 19000·0729 units; consequently, the addition of the jacketed surfaces of the piston to those of the cylinder increased the economic gain

$$\left(\frac{19452{\cdot}7617 - 19000{\cdot}0729 \times 100}{19452{\cdot}7617} = \right)$$

2·3271 per centum.

In experiment F the total horse-power cost 20230·7613 units of heat per hour; in experiment L it cost 20653·5712 units; consequently, the addition of the jacketed surfaces of the piston to those of the cylinder *decreased* the economic gain

$$\left(\frac{20653{\cdot}5712 - 20230{\cdot}7613 \times 100}{20230{\cdot}7613} = \right)$$

2·0899 per centum.

The differences from the two sets of experiments being in opposite

directions, about equal, and small, show them to result from errors of observation, and, as they neutralize each other, the conclusion is warranted that the addition of the steam jacketed surfaces of the piston to those of the cylinder produced no sensible effect. As a corollary to this there follows that the cylinder jackets alone were efficient enough to prevent all or nearly all the cylinder condensation, leaving the piston jackets nugatory.

We are here met with the fact that the weight of water of condensation drained from the piston and from the cylinder jackets in experiment *G* have the relation of 1·0000 to 3·8179, and in experiment *L* the relation of 1·0000 to 3·6539, showing a greater abstraction of heat per unit of surface from the piston than from the cylinder jackets, and this heat must have been transferred to something. Now, as the experiments show it was not used to prevent cylinder condensation, it must have been conducted away by the piston-rod which was in metallic contact with the piston, extending from the latter in both directions through both ends of the cylinder, and thence into the free air, one end of the piston-rod being in metallic contact with a crosshead. This rod undoubtedly transferred the heat from the piston jackets to the external air, and thus caused the observed condensation of steam within them.

Railway Alarm-Whistle.—In order to prevent a train passing a danger signal during a fog or snow-storm without being seen by the engineer, the Southern Railway Company of France have attached to the locomotive a steam whistle, which is controlled by the signal. The whistle is connected with an insulated metallic brush placed under the engine. Between the rails there is a projecting contact bar, faced with copper, which is swept by the brush when the train passes. This contact piece is connected with the positive pole of a voltaic battery, the negative pole of which is in communication with a commutator on the signal post, from which a wire leads to the ground. When the signal is "line clear" the passage of the brush over the fixed contact produces no result; but when the signal marks "danger," the commutator brings the negative pole of the battery in direct communication with the ground, and when the brush passes over the contact the completion of the electric current causes the whistle to be sounded, so as to alarm the driver.—*L'Ingen. Univ.* C.

THE FLIGHT OF BIRDS AND THE MECHANICAL PRINCIPLES INVOLVED.

By A. C. Campbell.

The flight of birds has always been a favorite subject of investigation, and the conclusion has ever been that it is a feat of great strength.

The apparent ease and the swiftness with which the bird moves through the air cannot have failed to excite a spirit of wondering in the mind of the acute observer. How does he contrive to sustain himself against gravity, and how is it that he can acquire such great speed by means of the appliances at his command?

Are there not some hidden mechanical principles involved in his flight that lighten his task?

Before endeavoring to give the philosophy of flight, we will consider some of the mechanical effects and properties of the atmospheric air as a medium through which the bird wings his way.

The air, as we know, has weight and so it has inertia. It has perfect elasticity. Air in motion imparts its inertia to any object impeding its movement, and so arises what is understood as the force of winds.

It is a known law of winds that their pressure or force varies with the square of their velocity. Winds having velocities of 7, 14, 21, 41, 61, 82 and 92 miles per hour exert pressures respectively per square foot of 0·2, 0·9, 1·9, 7·5, 16·7, 30·7 and 37·9 pounds. From which we may conclude that a plane surface of five square feet, facing a wind of seven miles per hour, would receive a pressure of one pound. And the result would remain the same if the plane were moved at the rate of seven miles per hour against the air at a standstill. Five hundred square feet, in like manner, would support a weight of one hundred pounds and descend through the air at a rate of seven miles per hour.

Now if the plane be inclined to the direction of the wind or force of air, there would seemingly be a two-fold diminution of pressure, namely in the first place by a less proportion of air being intercepted, and secondly on account of a less proportion of pressure being

imparted. But in practice it does not hold true, since all of the particles of air are not turned sharply in a direction parallel with the plane.

After making many attempts to discover the relative pressures upon planes of variable degrees of inclination to the direction of the force of air, I finally lit upon the following simple device which gave very good results. I constructed a balance in such a way that the wind would take effect upon two plane surfaces of variable areas, and situated at variable distances from the fulcrum.

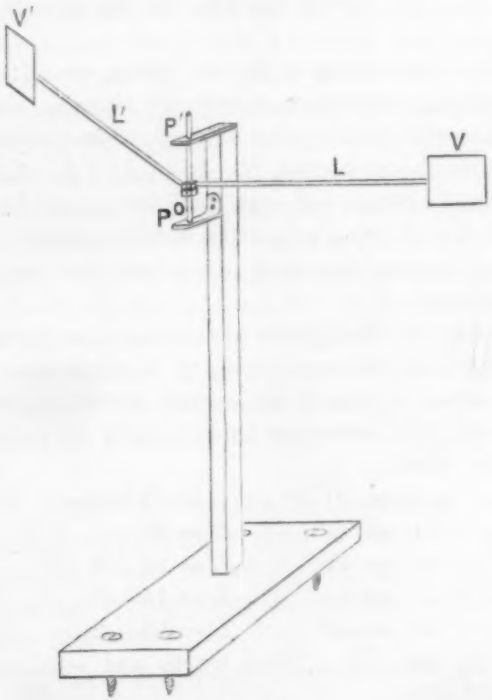


Fig. 1.

In the adjoining figure (1), V V' are the two planes fixed to the lever arms L L', the latter being firmly fixed to the spindle O by binding screws. The spindle revolves in a socket made in the lower lip or plate P, and passes through a small hole in the upper plate P'. The spindle has perfect freedom of movement and is nicely balanced.

If both planes are the same area (say ten square inches) and both

arms the same length, then there are two positions of equilibrium (supposing, all the time, that the plane V stands at right angles to the direction of the wind), namely, when both planes are at the same angle and when V' stands at an angle 30° with the direction of the wind. In other words, if (A) and (A') represent the angles which V and V' make, respectively, with the wind, then there is equilibrium when $(A) = 90°$ and $(A') = 90°$, also when $(A) = 90°$ and $(A') = 30°$, and this appears to hold true for variable pressures of wind. If (A') is made greater than 30° the pressure upon V' preponderates until the angle of about 42° is reached, when the pressure is at its maximum. As (A') is made less than 30° the pressure upon V preponderates.

The relative pressures upon the two planes, when (A') is variable, may be discovered in two ways, namely, by adjusting the lengths of the lever arms until equilibrium is attained, when the pressures would be expressed by the proportion $P : P' :: L' : L$. Likewise if the arms are retained constant and equal, and the area of the planes made variable, then the following proportion would answer $P : P' :: S' : S$, P and P' representing pressures per square foot, and S and S' the areas of the planes.

The following are a few results from actual experiment.

I fixed a plane of ten square inches at V and the same at V', then adjusted the arms at various angles, and moved the plane V' along the arm L' until the instrument balanced with the plane V standing normally to the wind.

$(A) = 90°$	$L = 19$ inches.
$A' = 30°$	$L' = 19$ "
$A' = 40°$	$L' = 15$ "
$A' = 42°$	$L' = 14{\cdot}5$ "
$A' = 45°$	$L' = 16$ "

Retaining the arms at a given length and equal, the following results were obtained

$V = 10$ sq. inches.	$A = 90°$
$V' = 10$ " "	$A' = 30°$
$V' = 9$ " "	$A' = 20°$
$V' = 6$ " "	$A' = 15°$

If a plane surface of one square foot be moved normally against the air at the rate of 21 miles per hour, the pressure or resistance would be 1·9 lbs. If the plane were inclined at an angle of 30°

with the direction of its movement, the pressure would remain the same, but the buoyancy against gravity would be expressed by 1·9 cos. 30° = 1·64 lbs. while the horizontal resistance would be 1·9 sin. 30° = 0·95.

If the plane be inclined to within 15° of the direction of movement, it will receive a normal pressure of $\frac{6}{10}$ of 1·9 lbs. = 1·14 lbs., 1·14 sin. 15° = 0·295 lb., 1·14 cos. 15° = 1·1 lb. As the plane becomes nearly parallel with the direction of the force of air, a less proportion of it is intercepted and imparted, but as much as is received by the plane, the greater part gives an upward buoyancy, while a very small horizontal resistance is offered. If it be inclined to 5° then the proportion would be horizon. resis. : vertical buoyancy :: 1 : 11·43.

A bird in his flight moves against the air with such velocity that he needs to make but little effort to sustain himself against gravity, so allowing the greater portion of his strength for propulsion.

A plane moving horizontally through the air, and with such velocity and inclination that the component of the lifting force is equal to the force of gravity, then it will continue to move in the same horizontal direction. And we may say, generally, that a plane moving in any direction will continue to move in the same direction, provided, always, that the component of the force of air at right angles to the path, and the component of gravity also at right angles to the path, are in equilibrium. The component of gravity parallel with the path will accelerate or retard as the plane is inclined downward or upward.

Velocity is power or advantage by whatsoever means attained, whether by force of gravity, by force of air, or (in the case of the bird) by muscular effort. A bird moving against a wind derives a two-fold advantage, namely, from the combined velocities of the wind and his bodily movement.

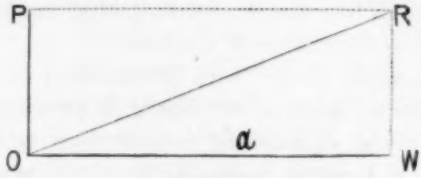


Fig. 2.

Some strange effects of the force of winds arise from combined movements.

Let $W\ O$ (Fig. 2) represent the velocity and direction of a wind, and $O\ P$ the velocity and direction of a plane maintaining a position at right angles to its path. Let $a = 30°$. It is evident that such combined movements are equivalent to a movement in velocity and direction marked by $O\ R$, supposing the air at a stand-still. But it has been demonstrated by experiment that a plane, holding an angle of 30° with its path, receives the same normal pressure as when at an angle of 90°.

$O\ R = 2\ P\ O$, and the pressures being in the ratio of the squares of the velocities, would be as 1 : 4.

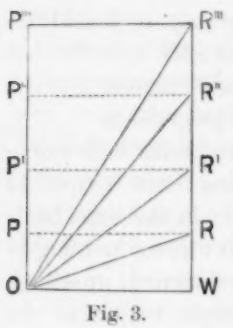


Fig. 3.

The angle (a) and the directions $O\ P$ and $W\ O$ may vary, yet the demonstration will hold true, provided the correct value is known of the normal pressure upon the plane at the angle (a) to its resultant path.

The vexed question of the ice yacht comes under the head of combined movements. Let $W\ O$ (Fig. 3) be the velocity and direction of a wind taking effect upon a plane occupying the position $O\ R$, and (a) the angle between $W\ O$ and $O\ R$. Let $O\ P$ be the path of the plane.

It matters not whether the wind move against the plane, or the plane move with the same velocity against the air at a stand-still. It is evident that if a plane move parallel with itself it will encounter no resistance of air. Passing from O to R is the two-fold movement $O\ W$ and $O\ P$. But $W\ O$ is the velocity and direction of a wind which, when substituted for the movement of the plane, makes it equivalent to the plane moving from O to P in the same time that the air passes from W to O. Likewise with $O\ R'$, $O\ R''$, $O\ R'''$, $O\ R''''$, etc. Every possible case may be referred to the parallelogram and demonstrated in like manner, remembering that the pressure is at all times normal to the surface of the plane.

A plane at an angle of 30° with the direction of a wind receives the same pressure as when at 90°, but if R represent the velocity of wind, R sin. a would express the velocity with which either plane would move in a direction perpendicular to the plane, supposing no resistance. R sin. $90° = R$. R sin. $30° = \frac{1}{2}\ R$.

If the inclined plane move with the wind, of course the velocity would be the same as that of the wind, but the pressure tending to

urge the plane in that direction would be one-half of that taking effect upon the normal plane, which is as it should be, since only one-half as much air is intercepted by the inclined plane.

A force of air coming in contact with an inclined plane is turned with the plane, and so long as the force continues there is a stratum of air passing down and parallel with the surface, and the constantly approaching air, instead of coming in contact with, and imparting its force directly to the plane, encounters and imparts its force to a belt of air; so the initial force of air is resolved into a force of pressure of an elastic medium acting at all times normally to the surface.

Each and every particle of air having a certain quantity of accumulated energy will impart its full effect of pressure, either directly or indirectly, gradually or abruptly, provided such particles are turned on account of the plane, more or less from their initial direction.

They may impart their effect directly by coming immediately in contact with the plane, or indirectly by imparting their pressure to other particles, and they in turn to others or a series of particles.

They may impart their effect gradually by a gradual change of direction, or abruptly by an abrupt change of direction. The quantity of pressure imparted by every particle is dependent upon the degree of change of direction.

It is a principle of mechanics that any force or forces will seek paths of most ready relief, and the principle should hold true in the case of a force of air intercepted by a surface.

A particle may begin to change from its initial direction at some distance before reaching the plane, and altogether there would be a system of arrangement and movement of the particles, arising from the pent up forces seeking paths of least resistance. After the system has become thoroughly established there is a constant minimum pressure imparted to the intervening object.

If a surface be brought instantly into cross section with a force of air, there will be an impulsive force imparted from the suddenly arrested movement of the column of air intercepted. From this there will arise a compression of air until its inertia permits it to escape from the surface and establish the system of movement referred to. The pressure is greatly augmented but of short duration.

We will suppose a flow of air to be passing through a long tube.

Now, if the discharging end be suddenly closed, the air coming in contact with the closed end will impart its inertia at once, while the

air throughout the length of the tube will continue to move, but with a diminished velocity. The particles nearest the seat of pressure will be more rapidly impeded, while those more remote will suffer only a gradual retardation. At the instant when the entire column is at a stand still, and possessed of an equilibrium of forces, then there will be a maximum of pressure at the closed end, with an arithmetical diminution of pressure toward the inlet. There will be a gradation of pressures along the sides of the tube, the same as the compression of air throughout its volume.

Now it is evident, if the air were not confined by the walls of the tube, that a lateral movement would take place in the direction of the strongest pressure, having to overcome the inertia of the air moved. This lateral movement would not only be that in line with the opposing surface, but also that extending in all directions, acting as walls in a degree like the walls of the tube.

The moment the air is intercepted that portion in contact with the surface makes the first move to escape, because of the excess of pressure brought to bear upon it. Then follow in succession portions of air more distant.

In the bird's flight it is an object to prevent this too hasty escape of the compressed air, so that more energy may accumulate and impart its effect. A force of air encountering a rigid or irresistible surface is turned from its initial direction on the slightest increase of pressure; but if the surface be elastic, or to a degree non-resistant, then the first imprint of pressure will be received and held in suspense by the receding parts of the surface until the more distant particles of air have arrived and added their burden of energy.

The density of air varies with its pressure, and its inertia increases with its density, so that when the pressure is augmented it has greater persistency against the tendency to a set movement of escape. Again, the opposing surface may be of such nature in its elementary parts as to obstruct the lateral escape by a species of entanglement of the individual particles of air and their inertias.

Air is possessed of a physical property (that of cohesion) which is of vast worth in its relation to our problem. All varieties of matter are possessed of cohesion in greater or less degree. The different degrees of cohesion give rise to solidity, plasticity and viscosity. All solid or rigid substances, so called, are more or less plastic, and all liquids and gases are more or less viscous. Under the effect of impul-

sive forces, plastic substances are as if solid, and viscous substances are as if plastic.

The air in effect behaves as a solid when subjected to impulsive forces of greatest intensity. A case in point is the explosion of nitroglycerine upon the surface of a solid. The mass is ruptured into fragments as if struck by some heavy weight. After the shock the air relieves itself as rapidly as the friction of cohesion and inertia permit.

Work in its mechanical sense is made up of two factors, namely, mass and velocity. $W = \frac{1}{2} M V^2$ is the most general expression, (W) is the quantity of work, (M) the mass or quantity of matter, and (V) the velocity with which it is moved.

Then it will appear, from all that has been said, that the work of velocity rather than the work of mass is the most advantageous source of relief in the bird's every effort. By whatsoever means he may attain velocity, he secures a corresponding relief of duty, and every move of increased velocity given to his wings in opposition to resistances is likewise an economy of power; an increase of velocity permitting a decrease of area of wing, so affording a relief of work. We must avoid the idea that there is of necessity a certain quantity of work for the bird to do, and that he can by no means avoid the set task.

The bird strikes downward with his wings, and secures a pressure of air, which he manages to retain by defeating its every effort to escape. At first his wings decline to the rear, but owing to their torsion and flexure the increasing pressure of air finds relief only through a circuitous path, and at the completion of the stroke the extremities of the wings are tilted rapidly upward.

The wing is so strangely constructed, and its parts are so well adapted to the uses for which they answer, it may be well to study it in detail. It will be necessary to make a few practical demonstrations in order to do our work understandingly.

Let (a, o) (Fig. 4) be a series of elastic surfaces, b, b', b'', etc., and each one confined by its upper edge so that a force of air from the direction denoted by the arrows will cause the surfaces to revolve and close the passages (c, c', c''). This done, the air is defeated in its movement, and a shock or force of impulse secured.

If, instead of the free movement of the slats, they be supposed to have an elastic resistance against being closed, then a force of air of variable intensity will cause them to open and close in rapid succession,

as the force and resistance alternately hold sway. The slats having weight, their inertia in the to and fro movement would act an important part in timing the vibrations to the degree of pressure, and there would be a rhythmical play of impulses or pulsations.

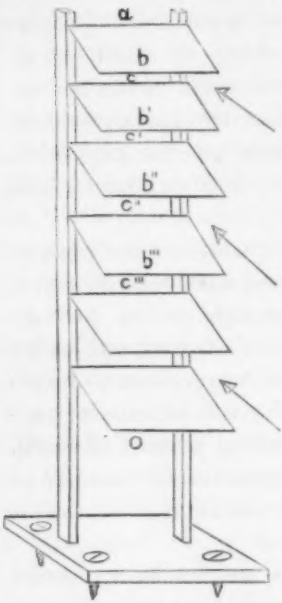


Fig. 4.

Another demonstration may serve to give a more accurate idea of this force of impulse.

Let *a o* (Fig. 5) be a plane surface moving adrift with a wind of any velocity, the plane having the same velocity as the wind. There can be, as yet, no interferenec. Let (*d*) be a fixed point of resistance. The plane will continue to move until it arrives at (*d*), where it will be instantly stopped, thus causing the intercepted column of air to be as quickly stopped and deprived of its moving force. There would be an arrested movement of the air on the two sides of the plane; the difference of the two pressures would be the effective pressure.

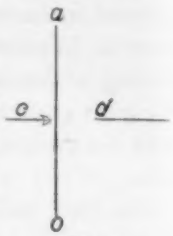


Fig. 5.

So far we have only looked to the force of air as taking effect in one direction; but in the bird's flight there is requisite a lifting and a propelling force.

A force of air after having imparted in one direction a pressure due to its living force may yet impart another pressure in another direction without losing any of its accumulated energy, provided it imparts no movement.

When the bird strikes downward with his wings the resistance of the air acts upward, thus supporting his weight, and also giving him a forward impetus, owing to the escape of the pressure of air to the rear.

The wing, as is well known, is made up of long, stout feathers with quill extremities inserted in cartilaginous sockets of the bird's arm. These quill extremities have muscular attachments, so that the bird has power to revolve the feathers within their sockets. Each feather

is made up of a midrib extending through its entire length, the quill or socket extremity of which is tubular, rigid and larger than the balance. It is translucent, horny and tough, well calculated for strength and at the same time lightness. The balance of the midrib is pithy and not so rigid. It grows smaller and much lighter toward the point. Radiating from both sides are feather branchlets and sub-branchlets, which, from their close proximity, give the feather a smooth surface-like appearance.

Supposing the bird's wing outstretched, with the quill feathers pointing to the rear. The branchlets that radiate inwardly toward the bird and *underlap* form a more extensive surface than the banchlets of the opposite side of the feather, which *overlap*. The lapping may be of position, without contact, the bird having power to adjust the feathers.

Supposing the surfaces to be properly adjusted, then, as he strikes downward with his wings, a force of air taking effect upon the underlapping surfaces, causes them to collide with the overlapping surfaces, thus abruptly stopping the initial movement of air and its initial energy. This momentary shock or impulse given to the wings serves as a foot-hold to sustain the bird against the tendency of gravity, and as the strokes are made in rapid succession, he may be said to walk upon the air.

The compressed air may seek relief by passing along the surfaces of the wings and escaping from their extreme margins, after having yielded its store of energy first to sustain and then to propel. Or it may find more ready relief by penetrating the network structure of the feathers.

Of these two channels of escape the latter one is sought by those particles of air that come immediately in contact with the wing-surface at the instant of the shock, and are the most active and are possessed of the greatest energy. If permitted, they would destroy the vantage-ground by generating a radial movement of escape. Hence the strangely beautiful structure of the feather.

The pressure of air is first caught, directed and manipulated by the branchlets, and then by the sub-branchlets, when it is allowed to escape from its entanglement. These sub-branchlets radiate from the branchlets, the latter being as midribs. These secondary midribs are discoid in section, and have a tough horny exterior with a pithy centre. See Fig. 6.

b, *b'*, *b''*, etc., are the branchlets or secondary midribs, on each side of which are the sub-branchlets *c*, *c'*, *c''*, etc., overlapping, and *d*, *d'*, *d''* underlapping. The former are longer and more prominent, and the latter form a much less areal surface. These sub-branchlets have their lateral borders barbed with little hooks or loops that enable the over- and underlapping surfaces to cling together, and they hold with a persistent grasp so long as the surfaces are in contact.

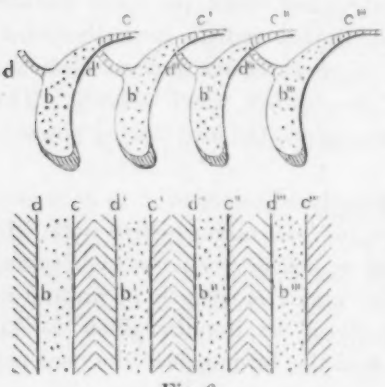


Fig. 6.

From the character of these different parts of the feather and their arrangement with reference to one another it is evident that the elastic force of air taking effect upon them causes a rhythmical vibration, each and every part securing a series of rapid pulsations.

An average feather has about one thousand branchlets, and one million five hundred thousand sub-branchlets, each one of which lends a helping hand to lighten the bird's task. In proportion as there is a greater percussion, the rhythmical pulsations are more frequent and stronger. In the flight of the pigeon and of some other birds this rhythm gives rise to a musical whiz.

So far we have only mentioned the bird proper, and there are almost an infinity of creatures of flight, and one of the most humble is the bat.

The bat, in lifting his wings, raises the front margins more rapidly than the balance of the wing, so that a downward turned fold is given to the thin elastic membrane. At the completion of this fold or loop he thrusts his wing downward, so that the body of air is brought to impinge upon its convexity, suddenly reversing it and bagging the force of air.

I tried the following simple experiment to demonstrate the character of this force. The arm (*c d*) (Fig. 7) is made of dry hickory and tapers toward *d*. (*b d*) is a ring or hoop firmly attached to (*c d.*) (*c d*) is mortised with glue to a thick and heavy block of wood. The hoop is covered with a loosely fitting membrane, or paper.

To make the experiment it is only necessary to pull the spring (*c d*) in a direction normally to the surface of the membrane, and then "let fly." The sudden impact of air against the surfaces of the membrane gives two loud reports, the second or reactionary stroke being louder and consequently the stronger. Stout paper may be easily burst by the impact, the report being like that of a pistol.

The experiment may be varied by substituting wire gauze for the membrane and suspending tissue paper before and at a distance from the hoop. The gauze offers little resistance to the movement of the spring, but is greatly impeded by the thin paper on account of its imperviousness to air. In this case also a loud report is given, which is proof of great concussion of the air.

Fig. 7.

It may be proper to say something of the little fly. How does he accomplish such wondrous bodily movements, his wings being so light and delicately slender? It cannot be discovered that he has much power of muscle, and yet it does seem that he must needs make considerable effort to overcome the inertia of his weight in his rapid starts from rest.

It has been shown that in proportion as the air is acted upon more quickly does it exercise greater resistance, and that in proportion as any winged creature strikes the air more quickly, may his wings be smaller and the actual work lessened in great degree. So we may conclude that the fly profits by the rapid movement of his wings. And that such is the case we may be further convinced by recording the musical note sounded by his wings. Knowing that they must move with great velocity, we must conclude that they do not move normally against the air, but rather at an angle, cutting the air upward, downward and laterally, the torsion of the wings and their delicate elasticity regulating their angular inclinations, *and they are as if smaller under increased velocities.* His wings are so exceedingly light that he needs make but little effort against their inertia. Besides, if they move through curvilinear paths without undergoing accelerated and retarded movements, then is the inertia continuous and self-sustaining.

In conclusion we may say that flight, whether of the bird, the bat or the fly, is not the herculean task of our wonted belief, but rather one of pleasurable ease, unaccompanied by the impediments that clog the way of the creatures that plod the earth.

ON THE MODERN DEVELOPMENT OF FARADAY'S CONCEPTION OF ELECTRICITY.

By Professor Helmholtz.

Abstract of the Faraday Lecture read before the Chemical Society, England, April 5th, 1881.

The majority of Faraday's own researches were connected, directly or indirectly, with questions regarding the nature of electricity, and his most important and most renowned discoveries lay in this field. The facts which he has found are universally known. Nevertheless, the fundamental conceptions by which Faraday has been led to these much-admired discoveries have not been received with much consideration. His principal aim was to express in his new conceptions only facts, with the least possible use of hypothetical substances and forces. This was really a progress in general scientific method, destined to purify science from the last remnants of metaphysics. Now that the mathematical interpretations of Faraday's conceptions regarding the nature of electric and magnetic force has been given by Clerk Maxwell, we see how great a degree of exactness and precision was really hidden behind his words, which to his contemporaries appeared so vague or obscure; and it is astonishing in the highest to see what a large number of general theories the methodical deduction of which requires the highest powers of mathematical analysis, he has found by a kind of intuition, with the security of instinct, without the help of a single mathematical formula.

The electrical researches of Faraday, although embracing a great number of apparently minute and disconnected questions, all of which he has treated with the same careful attention and conscientiousness, are really always aiming at two fundamental problems of natural philosophy, the one more regarding the nature of physical forces, or of forces working at a distance; the other, in the same way, regarding chemical forces, or those which act from molecule to molecule, and the relation between these and the first.

The great fundamental problem which Faraday called up anew for discussion was the existence of forces working directly at a distance without any intervening medium. During the last and the beginning

of the present century, the model after the likeness of which nearly all physical theories had been formed was the force of gravitation acting between the sun, the planets and their satellites. It is known how, with much caution and even reluctance, Sir Isaac Newton himself proposed his grand hypothesis, which was destined to become the first great and imposing example, illustrating the power of true scientific method.

But then came Oerstedt's discovery of the motions of magnets, under the influence of electric currents. The force acting in these phenomena had a new and very singular character. It seemed as if it would drive a single isolated pole of a magnet in a circle around the wire conducting the current, on and on without end, never coming to rest. Faraday saw that a motion of this kind could not be produced by any force of attraction or repulsion, working from point to point. If the current is able to increase the velocity of the magnet, the magnet must react on the current. So he made the experiment, and discovered induced currents; he traced them out through all the various conditions under which they ought to appear. He concluded that somewhere in a part of the space traversed by magnetic force, there exists a peculiar state of tension, and that every change of this tension produces electromotive force. This unknown hypothetical state he called provisionally the electrotonic state, and he was occupied for years and years in finding out what was this electrotonic state. He discovered at first, in 1838, the dielectric polarization of electric insulators, subject to electric forces. Such bodies show, under the influence of electric forces, phenomena perfectly analogous to those exhibited by soft iron under the influence of the magnetic force. Eleven years later, in 1849, he was able to demonstrate that all ponderable matter is magnetized under the influence of sufficiently intense magnetic force, and at the same time he discovered the phenomena of diamagnetism, which indicated that even space, devoid of all ponderable matter, is magnetizable; and now with quite a wonderful sagacity and intellectual precision, Faraday performed in his brain the work of a great mathematician without using a single mathematical formula. He saw, with his mind's eye, that by these systems of tensions and pressures produced by the dielectric and magnetic polarization of space which surrounds electrified bodies, magnets or wires conducting electric currents, all the phenomena of electro-static, magnetic, electro-magnetic attraction, repulsion and induction could be explained, with-

out recurring at all to forces acting directly at a distance. This was the part of his path where so few could follow him; perhaps a Clerk Maxwell, a second man of the same power and independence of intellect, was necessary to reconstruct in the normal methods of science the great building, the plan of which Faraday had conceived in his mind and attempted to make visible to his contemporaries.

Nevertheless the adherents of direct action at a distance have not yet ceased to search for solutions of the electro-magnetic problem. The present development of science, however, shows, as I think, a state of things very favorable to the hope that Faraday's fundamental conceptions may in the immediate future receive general assent. His theory, indeed, is the only existing one which is at the same time in perfect harmony with the facts observed, and which at least does not lead into any contradiction against the general axioms of dynamics.

It is not at all necessary to accept any definite opinion about the ultimate nature of the agent which we call electricity.

Faraday himself avoided as much as he could giving any affirmative assertion regarding this problem, although he did not conceal his disinclination to believe in the existence of two opposite electric fluids.

For our own discussion of the electro-chemical phenomena, to which we shall turn now, I beg permission to use the language of the old dualistic theory, because we shall have to speak principally on relations of quantity.

I now turn to the second fundamental problem aimed at by Faraday, the connection between electric and chemical force. Already, before Faraday went to work, an elaborate electro-chemical theory had been established by the renowned Swedish chemist, Berzelius, which formed the connecting-link of the great work of his life, the systematization of the chemical knowledge of his time. His starting point was the series into which Volta had arranged the metals according to the electric tension which they exhibit after contact with each other. A fundamental point which Faraday's experiment contradicted was the supposition that the quantity of electricity collected in each atom was dependent on their mutual electro-chemical differences, which he considered as the cause of their apparently greater chemical affinity. But although the fundamental conceptions of Berzelius' theory have been forsaken, chemists have not ceased to speak of positive and negative constituents of a compound body. Nobody

can overlook that such a contrast of qualities, as was expressed in Berzelius' theory, really exists, well developed at the extremities, less evident in the middle terms of the series, playing an important part in all chemical actions, although often subordinated to other influences.

When Faraday began to study the phenomena of decomposition by the galvanic current, which, of course, were considered by Berzelius as one of the firmest supports of his theory, he put a very simple question; the first question, indeed, which every chemist speculating about electrolysis ought to have answered. He asked, What is the quantity of electrolytic decomposition if the same quantity of electricity is sent through several electrolytic cells? By this investigation he discovered that most important law, generally known under his name, but called by him the law of definite electrolytic action.

Faraday concluded from his experiments that a definite quantity of electricity cannot pass a voltametric cell containing acidulated water between electrodes of platinum without setting free at the negative electrode a corresponding definite amount of hydrogen, and at the positive electrode the equivalent quantity of oxygen, one atom of oxygen for every pair of atoms of hydrogen. If instead of hydrogen any other element capable of substituting hydrogen is separated from the electrolyte, this is done also in a quantity exactly equivalent to the quantity of hydrogen which would have been evolved by the same electric current.

Since that time our experimental methods and our knowledge of the laws of electrical phenomena have made enormous progress, and a great many obstacles have now been removed which entangled every one of Faraday's steps, and obliged him to fight with the confused ideas and ill-applied theoretical conceptions of some of his cotemporaries. We need not hesitate to say that the more experimental methods were refined, the more the exactness and generality of Faraday's law was confirmed.

In the beginning Berzelius and the adherents of Volta's original theory of galvanism, based on the effects of metallic contact, raised many objections against Faraday's law. By the combination of Nobili's astatic pairs of magnetic needles with Schweigger's multiplicator, a coil of copper wire with numerous circumvolutions, galvanometers became so delicate that the electro-chemical equivalent of the smaller currents they indicated was imperceptible for all chemical methods. With the newest galvanometers you can very well observe currents which would

want to last a century before decomposing one milligram of water, the smallest quantity which is usually weighed on chemical balances. You see that if such a current lasts only some seconds or some minutes, there is not the slightest hope to discover its products of decomposition by chemical analysis. And even if it should last a long time the feeble quantities of hydrogen collected at the negative electrode can vanish, because they combine with the traces of atmospheric oxygen absorbed by the liquid. Under such conditions a feeble current may continue as long as you like without producing any visible trace of electrolysis, even not of galvanic polarization, the appearance of which can be used as an indication of previous electrolysis. Galvanic polarization, as you know, is an altered state of the metallic plates which have been used as electrodes during the decomposition of an electrolyte. Polarized electrodes, when connected by a galvanometer, give a current which they did not give before being polarized. By this current the plates are discharged again and returned to their original state of equality.

This depolarizing current is indeed a most delicate means of discovering previous decomposition. I have really ascertained that under favorable conditions one can observe the polarization produced during some seconds by a current which decomposes one milligram of water in a century.

Products of decomposition cannot appear at the electrodes without motions of the constituent molecules of the electrolyte throughout the whole length of the liquid. This subject has been studied very carefully and for a great number of liquids, by Prof. Hittorff, of Münster, and Prof. G. Wiedemann, of Leipsic.

Prof. F. Kohlrausch, of Würzburg, has brought to light the very important fact that in diluted solutions of salts, including hydrates of acids and hydrates of caustic alkalies, every atom under the influence of currents of the same density moves on with its own peculiar velocity, independently of other atoms moving at the same time in the same or in opposite directions. The total amount of chemical motion in every section of the fluid is represented by the sum of the equivalents of the cation gone forwards and of the anion gone backwards, in the same way as in the dualistic theory of electricity, and the total amount of electricity flowing through a section of the conductor corresponds to the sum of positive electricity going forwards and negative electricity going backwards.

This established, Faraday's law tells us that through each section of an electrolytic conductor we have always equivalent electrical and chemical motion. The same definite quantity of either positive or negative electricity moves always with each univalent ion, or with every unit of affinity of a multivalent ion, and accompanies it during all its motions through the interior of the electrolytic fluid. This we may call the electric charge of the atom.

Now the most startling result, perhaps, of Faraday's law is this: If we accept the hypothesis that the elementary substances are composed of atoms we cannot avoid concluding that electricity also, positive as well as negative, is divided into definite elementary portions, which behave like atoms of electricity. As long as it moves about on the electrolytic liquid each atom remains united with its electric equivalent or equivalents. At the surface of the electrodes decomposition can take place if there is sufficient electromotive power, and then the atoms give off their electric charges and become electrically neutral.

Now arises the question, Are all these relations between electricity and chemical combination limited to that class of bodies which we know as electrolytes? In order to produce a current of sufficient strength to collect enough of the products of decomposition without producing too much heat in the electrolyte, the substance which we try to decompose ought not to have too much resistance against the current. But this resistance may be very great, and the motion of the ions may be very slow, so slow indeed that we should need to allow it to go on for hundreds of years before we should be able to collect even traces of the products of decomposition; nevertheless all the essential attributes of the process of electrolysis could subsist. If you connect an electrified conductor with one of the electrodes of a cell filled with oil of turpentine, the other with the earth, you will find that the electricity of the conductor is discharged unmistakably more rapidly through the oil of turpentine than if you take it away and fill the cell only with air.

Also in this case we may observe polarization of the electrodes as a symptom of previous electrolysis. Another sign of electrolytic conduction is that liquids brought between two different metals produce an electromotive force. This is never done by metals of equal temperature, or other conductors which, like metals, let electricity pass without being decomposed.

The same effect is also observed even with a great many rigid bodies,

although we have very few solid bodies which allow us to observe this electrolytic conduction with the galvanometer, and even these only at temperatures near to their melting-point. It is nearly impossible to shelter the quadrants of a delicate electrometer against being charged by the insulating bodies by which they are supported.

In all the cases which I have quoted one might suspect that traces of humidity absorbed by the substance or adhering to their surface were the electrolytes. I show you, therefore, this little Daniell's cell, in which the porous septum has been substituted by a thin stratum of glass. Externally all is symmetrical at both poles; there is nothing in contact with the air but a closed surface of glass, through which two wires of platinum penetrate. The whole charges the electrometer exactly like a Daniell's cell of very great resistance, and this it would not do if the septum of glass did not behave like an electrolyte. All these facts show that electrolytic conduction is not at all limited to solutions of acids or salts.

Hitherto we have studied the motions of ponderable matter as well as of electricity, going on in an electrolyte. Let us study now the forces which are able to produce these motions. It has always appeared somewhat startling to everybody who knows the mighty power of chemical forces, the enormous quantity of heat and of mechanical work which they are able to produce, and who compares with it the exceedingly small electric attraction which the poles of a battery of two Daniell's cells show. Nevertheless this little apparatus is able to decompose water.

The quantity of electricity which can be conveyed by a very small quantity of hydrogen, when measured by its electrostatic forces, is exceedingly great. Faraday saw this, and has endeavored in various ways to give at least an approximate determination. The most powerful batteries of Leyden jars, discharged through a voltameter, give scarcely any visible traces of gases. At present we can give definite numbers. The result is that the electricity of 1 m.grm. of water, separated and communicated to two balls, 1 kilometre distant, would produce an attraction between them, equal to the weight of 25,000 kilos.

The total force exerted by the attraction of an electrified body upon another charged with opposite electricity is always proportional to the quantity of electricity contained in the attracting as on the attracted body, and therefore even the feeble electric tension of two Daniell's

elements, acting through an electrolytic cell upon the enormous quantities of electricity with which the constituent ions of water are charged, is mighty enough to separate these elements and to keep them separated.

We now turn to investigate what motions of the ponderable molecules require the action of these forces. Let us begin with the case where the conducting liquid is surrounded everywhere by insulating bodies. Then no electricity can enter, none can go out through its surface, but positive electricity can be driven to one side, negative to the other, by the attracting and repelling forces of external electrified bodies. This process going on as well in every metallic conductor is called "electrostatic induction." Liquid conductors behave quite like metals under these conditions. Prof. Wüllner has proved that even our best insulators, exposed to electric forces for a long time, are charged at last quite in the same way as metals would be charged in an instant. There can be no doubt that even electromotive forces going down to less than $\frac{1}{100}$ Daniell produce perfect electrical equilibrium in the interior of an electrolytic liquid.

Another somewhat modified instance of the same effects is afforded by a voltametric cell containing two electrodes of platinum, which are connected with a Daniell's cell, the electromotive force of which is insufficient to decompose the electrolyte. Under this condition the ions carried to the electrodes cannot give off their electric charges. The whole apparatus behaves, as was first accentuated by Sir W. Thomson, like a condenser of enormous capacity.

Observing the polarizing and depolarizing currents in a cell containing two electrodes of platinum, hermetically sealed and freed of all air, we can observe these phenomena with the most feeble electromotive forces of $\frac{1}{1000}$ Daniell, and I found that down to this limit the capacity of the platinum surfaces proved to be constant. By taking greater surfaces of platinum, I suppose it will be possible to reach a limit much lower than that. If any chemical force existed besides that of the electrical charges which could bind all the pairs of opposite ions together, and require any amount of work to be vanquished, an inferior limit to the electromotive forces ought to exist, which forces are able to attract the atoms to the electrodes and to charge these as condensers. No phenomenon indicating such a limit has as yet been discovered, and we must conclude, therefore, that no

other force resists the motions of the ions through the interior of the liquid than the mutual attractions of their electric charges.

On the contrary, as soon as an ion is to be separated from its electrical charge we find that the electrical forces of the battery meet with a powerful resistance, the overpowering of which requires a good deal of work to be done. Usually the ions, losing their electric charges, are separated at the same time from the liquid; some of them are evolved as gases, others are deposited as rigid strata on the surface of the electrodes, like galvanoplastic copper. But the union of two constituents having powerful affinity to form a chemical compound, as you know very well, produces always a great amount of heat, and heat is equivalent to work. On the contrary, decomposition of the compound substances requires work, because it restores the energy of the chemical forces, which has been spent by the act of combination.

Metals uniting with oxygen or halogens produce heat in the same way, some of them, like potassium, sodium, zinc, even more heat than an equivalent quantity of hydrogen; less oxidizable metals, like copper, silver, platinum, less. We find, therefore, that heat is generated when zinc drives copper out of its combination with the compound halogen of sulphuric acid, as in the case in a Daniell's cell.

If a galvanic current passes through any conductor, a metallic wire, or an electrolytic fluid, it evolves heat. Mr. Prescott Joule was the first who proved experimentally that if no other work is done by the current, the total amount of heat evolved in galvanic circuit during a certain time is exactly equal to that which ought to have been generated by the chemical actions which have been performed during that time. But this heat is not evolved at the surface of the electrodes, where these chemical actions take place, but is evolved in all the parts of the circuit, proportionally to the galvanic resistance of every part. From this it is evident that the heat evolved is an immediate effect, not of the chemical action, but of the galvanic current, and that the chemical work of the battery has been spent in producing only the electric action.

If we apply Faraday's law, a definite amount of electricity passing through the circuit corresponds to a definite amount of chemical decomposition going on in every electrolytic cell of the same circuit. According to the theory of electricity, the work done by such a definite quantity of electricity which passes, producing a current, is proportionate to the electromotive force acting between both ends of the

conductor. You see, therefore, that the electromotive force of a galvanic circuit must be, and is indeed, proportionate to the heat generated by the sum of all the chemical actions going on in all the electrolytic cells during the passage of the same quantity of electricity. In cells of the galvanic battery chemical forces are brought into action able to produce work; in cells in which decomposition is occurring work must be done against opposing chemical forces; the rest of the work done appears as heat evolved by the current, as far as it is not used up to produce motions of magnets or other equivalents of work.

Hitherto we have supposed that the ion with its electric charge is separated from the fluid. But the ponderable atoms can give off their electricity to the electrode, and remain in the liquid, being now electrically neutral. This makes almost no difference in the value of the electromotive force. For instance, if chlorine is separated at the anode, it will remain at first absorbed by the liquid; if the solution becomes saturated, or if we make a vacuum over the liquid, the gas will rise in bubbles. The electromotive force remains unaltered. The same may be observed with all the other gases. You see in this case that the change of electrically negative chlorine into neutral chlorine is the process which requires so great an amount of work, even if the ponderable matter of the atoms remains where it was.

The more the surface of the positive electrode is covered with negative atoms of the anion, and the negative with the positive ones of the cation, the more the attracting force of the electrodes exerted upon the ions of the liquid is diminished by this second stratum of opposite electricity covering them. On the contrary, the force with which the positive electricity of an atom of hydrogen is attracted towards the negatively charged metal increases in proportion as more negative electricity collects before it on the metal, and the more negative electricity collects behind it in the fluid.

Such is the mechanism by which electric force is concentrated and increased in its intensity to such a degree that it becomes able to overpower the mightiest chemical affiinities we know of. If this can be done by a polarized surface, acting like a condenser, charged by a very moderate electromotive force, can the attractions between the enormous electric charges of anions and cations play an unimportant and indifferent part in chemical affinity?

You see, therefore, if we use the language of the dualistic theory and treat positive and negative electricities as two substances, the phenomena are the same as if equivalents of positive and negative electricity were attracted by different atoms, and perhaps also by the different values of affinity belonging to the same atom with different force. Potassium, sodium, zinc, must have strong attraction to a positive charge; oxygen, chlorine, bromine to a negative charge.

Faraday very often recurs to this to express his conviction that the forces termed chemical affinity and electricity are one and the same. I have endeavored to give you a survey of the facts in their mutual connection, avoiding, as far as possible, introducing other hypotheses, except the atomic theory of modern chemistry. I think the facts leave no doubt that the very mightiest among the chemical forces are of electric origin. The atoms cling to their electric charges and the opposite electric charges cling to the atoms. But I don't suppose that other molecular forces are excluded, working directly from atom to atom. Several of our leading chemists have begun lately to distinguish two classes of compounds, molecular aggregates and typical compounds. The latter are united by atomic affinities, the former not. Electrolytes belong to the latter class.

If we conclude from the facts that every unit of affinity of every atom is charged always with one equivalent either of positive or of negative electricity, they can form compounds, being electrically neutral, only if every unit charged positively unites under the influence of a mighty electric attraction with another unit charged negatively. You see that this ought to produce compounds in which every unit of affinity of every atom is connected with one and only with one other unit of another atom. This is, as you will see immediately, indeed, the modern chemical theory of quantivalence, comprising all the saturated compounds. The fact that even elementary substances, with few exceptions, have molecules composed of two atoms, makes it probable that even in these cases electric neutralization is produced by the combination of two atoms, each charged with its electric equivalent, not by neutralization of every single unit of affinity.

But I abstain from entering into mere specialties, as, for instance, the question of unsaturated compounds; perhaps I have gone already too far. I would not have dared to do it if I did not feel myself sheltered by the authority of that great man who was guided by a never-erring instinct of truth. I thought that the best I could do for

his memory was to recall to the minds of the men, by the energy and and intelligence of whom chemistry has undergone its modern astonishing development, what important treasures of knowledge lie still hidden in the works of that wonderful genius. I am not sufficiently acquainted with chemistry to be confident that I have given the right interpretation, that interpretation which Faraday himself would have given perhaps, if he had known the law of chemical quantivalence, if he had had the experimental means of ascertaining how large the extent, how unexceptional the accuracy of his law really is; and if he had known the precise formulation of the law of energy applied to chemical work, and of the laws which determine the distribution of electric forces in space as well as in ponderable bodies transmitting electric current or forming condensers. I shall consider my work of to-day well rewarded if I have succeeded in kindling anew the interest of chemists for the electro-chemical part of their science.

RECENT ADVANCES IN PHOTOGRAPHY, NEGATIVE AND POSITIVE.

By JOHN CARBUTT.

Abstract of a Lecture delivered before the Franklin Institute, April 25, 1881.

Among the numerous civilizing and educational agencies of the nineteenth century that have been and are now benefitting mankind stand pre-eminent the Steam Engine, Electricity and Photography. Upon the two former I need not dwell before an audience of the Franklin Institute.

It may, however, be interesting, and perhaps to some instructive, to briefly trace the history of photography, before proceeding to the description and illustration of modern photography, negative and positive, this being the main object for which I have the honor to appear before you this evening.

Photography means literally writing by means of light, and is of much older origin than many suppose. The eminent Swedish chemist, Scheele, was the first to notice the decomposing action of light on compounds containing silver, and in 1777 obtained the first photograph of the solar spectrum.

The first attempt to render the action of light available in the repro-

duction of drawings was made about 1802 by Wedgwood and Davy, who, while they succeeded in obtaining images by aid of the sun's rays, were unable to fix or render unalterable those parts of the sensitive surface not acted upon by the light.

It was not, however, until the discovery by Sir John Herschel of the power of hyposulphite of soda to dissolve the salts of silver that are insoluble in water, that any real progress was made in this art. The discoveries of Daguerre, of France, and Talbot, of England, were made known to the world in 1839; for some years previous both had been experimenting to produce photogenic drawings by the aid of light and the camera obscura (the invention of Baptista Porto in the sixteenth century), Daguerre on metal and Talbot on paper.

Daguerre took a polished silver plate, made sensitive to light by exposing it to the vapor of iodine, and after exposure in the camera developed the image by the vapor of mercury.

Talbot used paper, coating the surface with a solution of iodide of potassium in water, and when dry again coating with an aqueous solution of nitrate of silver, drying and exposing in the camera, developing the image with gallo-nitrate of silver.

The Daguerreotype process, as given to the world, was but in a crude form, the sensitiveness being of a low degree, requiring 15 to 20 minutes' exposure in sunlight to obtain an impression, and the image not permanent; nevertheless, the results at that time were considered marvelous. On the process becoming known, men of science took up the study of Daguerreotyping, and speedily improved upon the results obtained by Daguerre. To M. Godard, of London, is due the credit of increasing the sensitiveness of the plates by using the vapor of bromine in addition to iodine, as employed by Daguerre, and to M. Fizeau, of Paris, the rendering of the impression permanent by giving the plate a slight gilding of gold. The Daguerreotype, while one of the most beautiful pictures ever produced by photography, owing to its reversed image and want of duplicating power, received its death-blow on the advent of Archer's collodion process in 1851, and was practiced for only a few years after that time.

The Calotype process of Fox Talbot, or Talbotype as it is generally named, was never a favorite, on account of the difficulty of getting rid of the effect of the grain or fibre of the paper on which the negative was made; but Le Gray, of Paris, removed this objection in a great measure by his improvement of waxing the paper negative.

This process was succeeded by the albumen process of Niepce de Saint Victor, albumen being used as the vehicle to hold the sensitive salts of silver on glass plates, as suggested by Sir John Herschel; although a slow process, it yielded negatives of fine quality, also positives, and is still extensively used in France in the production of transparencies for the lantern. Messrs. Langenheim Bros. and Francis Schreiber, of Philadelphia, as well as others in America, were successful workers of this process.

In 1851 F. Scott Archer, of London, as previously stated, gave to the world his collodion process, which, with slight modifications, has been used as he gave it for nearly thirty years, and is called by the profession the *wet process*. Its use is confined chiefly to the building or gallery of the photographer, the great difficulties involved in transporting the chemicals and "dark room" apparatus in a serviceable condition for out-door photographing restricting its use mainly to professionals. Since the advent of collodion constant effort has been made to prepare the sensitive plates in a dry state, with collodion or collodion and albumen combined, and with considerable success by both professional and amateur photographers; yet the most successful in preparing these plates felt seriously at times that a most essential quality—rapidity or sensitiveness—was lacking, as they required an exposure of from four to ten times as long as wet collodion plates. It was not until another vehicle for holding the sensitive salts of silver was found, that a rapidity of action equal to and exceeding the most sensitive wet collodion plate was attained, and dry-plate photography became practicable to the professional photographer.

In the new method gelatine is the material with which the sensitive salts of silver are combined, and plates are prepared of the most exalted sensitiveness. This process is not yet ten years old. To Dr. R. L. Maddox, of London, is due the credit of first publishing a formula for their preparation. For six or seven years very little notice was taken of it, but for the past two years the photographic world, or that part of it on the other side of the Atlantic, has become enthusiastic over it, and now the fever has reached American photographers, both amateur and professional.

This gelatino-bromide process, as it is generally called, is certainly a wonderful advance in the art science of photography, enabling impressions in the camera to be obtained in from one-sixth to one-tenth the time of the most rapid collodion plate hitherto employed. The pre-

paration of these "gelatino-bromide" plates is in brief as follows: To a solution of fine gelatine in water is added bromide of potassium or ammonium; in another portion of water is dissolved nitrate of silver; in a room lighted through dark ruby glass, the solution of silver is added by degrees to the bromide and gelatine, and well stirred. It must be kept in a fluid condition for some hours, at a moderate temperature, and, where great sensitiveness is required, for one to four days, or the time may be confined to an hour or two by using a higher degree of heat. It now remains only to free it from the nitrates of potassium or ammonium, formed during the making of the emulsion, which is done by pouring the emulsion into a porcelain dish and allowing it to set to a stiff jelly, after which it is broken up, washed in several changes of cold water, drained and remelted for use, and the plates are coated and dried, and are then ready for use, and may be kept any length of time. These plates are being rapidly adopted by the profession, not only for viewing, but for the regular practice of photography in the studio, as they require no preparation, but are ready at any and all times when the operator is prepared to make the exposure. For scientific explorations they are of great value. I have secured a few prints from negatives taken by the photographer on the Howgate Expedition to the Arctic regions, as well as some by professional and amateur photographers, on gelatine plates made in this city, and known as the "Keystone" brand. To convey to you some idea of the progress made in shortening the time of exposure in the camera, one of the pictures to be shown on the screen was said to have been taken in the 150th part of a second. Compare this with the fifteen minutes exposure given to the Daguerreotype spoken of, and you will find it to be one 270,000th part of that time. It would not be fair to claim for gelatine dry plates all the credit of securing these wonderful results; the perfection to which our optical instruments have been brought has much to do with it, and I have here to show you the most recent improvements in dry-plate apparatus, made by the Scovill Manufacturing Co., New York.

I will now exhibit to you a few slides made on gelatine plates from gelatine negatives, and then proceed with the remainder of my subject —positive photography and its improvements.

Reproducing the image of the negative on paper was first confined to Talbot's Calotype process. Plain chloride of silver paper was then used both for direct printing and gallic acid development and some

of the latter prints have stood the test of time better than any since made with the silver salts. Albumen paper was introduced about 1854—that is, paper coated with a layer of albumen containing a certain amount of chloride of ammonium or sodium and dried. It is sensitized by floating it on a solution of nitrate of silver. After drying it is printed under the negative, toned by passing it through a weak solution of chloride of gold, then into a solution of hyposulphite of soda, technically called the fixing-bath. After a thorough washing the picture is finished, so far as any chemical treatment is needed. This has been, and is yet, the staple process by which the greater bulk of positive impressions is produced. It was early discovered that the permanence of the prints was not assured, and various attempts have been made to replace the albumen print by one of a more durable nature. The process that at one time seemed destined to supplant it was the carbon process, which was adopted by some few photographers, to the exclusion of silver printing; but, after a thorough trial, it had to be abandoned for the old process. The carbon process finds but limited application in America, while in England it is made use of to a large extent in the reproduction of works of art.

The next process to attract public attention was the platinum process of W. Willis, Jr., of London, but now of New York. In this process it was aimed to replace the silver salt by the less oxidizable metal platinum. At first, while the process gave very beautiful results, it required chemical knowledge on the part of the operator, and so much care that it was practically valueless. About two years ago Mr. Willis discovered a method by which all these objectionable features were removed—the process much simplified—and reliable results obtained with ordinary care. This process, in its improved form, I shall now describe, and develop some prints before you.

Only four chemicals are made use of; they are ferric oxalate, potassic oxalate, potassic chloro-platinate and hydrochloric acid. One ounce of the ferric oxalate solution is taken, and from 40 to 60 grains of the potassic chloro-platinate is dissolved therein. This is the sensitizing solution, which is applied to the surface of the paper to be used, by means of a pad of flannel. The paper is allowed to become surface dry, and is then perfectly dried by the aid of heat. The exposure to light is made in the usual manner, either under the negative, or when an enlargement is desired, by the use of the solar camera or electric light. The exposed print is developed in or on a hot solu-

tion of potassic oxalate, and is then immersed in a weak bath of hydrochloric acid to dissolve out the iron salt left in the paper, and finally washed in three or four baths of plain water.

I will now conclude by developing some prints sent to me by Mr. Willis. You will observe a faint image on this sheet of paper, produced by the action of light; it is a picture in ferrous oxalate, the iron salt only being reduced from ferric oxalate to ferrous oxalate, the platinum salt being in intimate mixture only. Now if to a solution of ferrous oxalate in oxalate of potassa, a solution of platinum chloride be added, you will instantly see a decomposition of the platinum salt in the shape of a fine black powder; and this is what will take place as I now pass the print through this hot solution of oxalate of potash. You see, where the action of the light has been strongest, the greatest quantity of platinum is precipitated; this is caused by the dissolving of the ferrous oxalate by the potassic oxalate solution, when the two combined instantly reduce the platinum salt in situ, forming an image in platinum black, known as spongy platinum. Prints by this process have been subjected to the severest chemical tests without having their permanence affected in the least. I now pass the print into this water, acidified with hydrochloric acid, which will dissolve out the iron salt not acted on by the light—two or three changes in fresh water completing the process.

Another improvement in photographic printing is now being developed. It is the application of gelatino-bromide of silver to paper for enlargements and contact printing, the image being developed with ferrous oxalate. Gelatino-chloride of silver has also been used for contact printing in place of albumen paper. As yet these improvements have not been brought into use in America, but I am safe in saying there is no doubt they soon will be, as American photographers are too enterprising to let any improvement having merit lie idle.

Prophets without Honor.—The old proverb is illustrated by the inventors of thermometers. In England they use Fahrenheit's thermometer, the invention of a German. In Germany the thermometer of Reaumur, a Frenchman, is still the most common. In France and in many other countries the Centigrade thermometer, which was invented by the Swede Celsius, is universally adopted.—*Verkehrszeitung.* C.

MODERN CYANOTYPE PRINTING.

By Dr. J. M. Eder.

Although Herschel showed in 1842, by means of ferrocitrate and ferrocyanide of potassium, how positive cyanotypes were to be produced (blue lines upon a white ground), the process was one that has rarely been adopted in practice. It is so exceedingly difficult to obtain clear prints; the ground is always more or less blue.

Pellet was the first to show results of a faultless character, and in the last International Exhibition held at Paris, in 1878, some very fine positive cyanotypes were to be seen. The process, however, by which these were produced was not made known in its entirety. It was simply stated that the employment of slimy, gum-like substances was resorted to.

The details of a most excellent gum-iron process have now been given by Captain Pizzighelli; this method acts thoroughly well, and yields most satisfactory prints. Thirty volumes of a solution of gum arabic (water 5 parts, gum 1 part) are mixed with 8 volumes of an aqueous solution of citrate of iron and ammonia (water 2 parts, double salt 1 part), and to the mixture is added 5 volumes of an aqueous solution of perchloride of iron (water 2 parts, iron 1 part).

The mixture appears limpid at first, but soon grows thicker, and it should be used quickly after mixing it. It is applied to well-sized paper by means of a brush, the paper being dried in the dark.

Any design, drawing or tracing may be employed as negative, and, after printing a few minutes, the development is proceeded with. A solution of ferrocyanide of potassium (water 5 parts, ferrocyanide 1 part) is applied with a brush, and the picture appears almost instantly as a dark blue positive. As soon as every detail has appeared the print is quickly rinsed, and then put into a dish containing dilute hydrochloric acid (water 10, acid 1), when the image becomes clearer and brighter, the ground gets white and the gum-iron film is removed. After further washing the print is dried.

The printing and finishing of impressions proceed very rapidly; in fair weather it takes from one to two hours to carry out the whole process, preparing the paper into the bargain.

The whole secret of success lies in the use of the gum arabic, which forms with the iron salts an almost insoluble combination, covering the paper like a varnish. For this reason the pores of the paper are not filled with coloring matter where no color is wanted. The acid bath removes the varnish-like film of gum, and leaves the clear positive picture in blue behind.—*Photographic News.*

Sugar from Rags.—The manufacture of sugar from old rags is now carried on on a large scale. A German factory is regularly engaged in the business, treating the rags first by sulphuric acid so as convert them into dextrine. The dextrine is bleached, by means of milk of lime, and then submitted to a new sulphuric acid bath stronger than the first, after which, being transformed into crystals of glucose, it can be employed in jellies and confections. The glucose which is obtained by this process can be sold very cheaply, and it resembles chemically that which is derived from grapes. The attention of the German government has been called to the danger, in a hygienic point of view, which may arise from the use of this article.—*Chron. Ind.* C.

The Thermophone.—Mercadier, in his experiments upon radiophony, has succeeded in producing the desired effects by means of lights which are much more feeble than an ordinary gas jet, and even by invisible radiations. He first noticed that when powerful lights were used there was no need of concentrating lenses; it was sufficient to bring the lights as near as possible to the interrupting wheel, limiting the pencil of rays by means of a diaphragm of suitable opening, still nearer to the wheel. He then took a copper disc of two millimetres (·079 in.) thickness and about four centimetres (1·575 in.) diameter, fixed at a few centimetres from the diaphragm, and gradually heated the diaphragm upon the face opposed to the wheel by means of an oxy-hydrogen light. He thus obtained a source of radiations at first invisible, but of which the temperature could be gradually raised to a dull red and to a bright red. In the latter case the sounds produced are very plainly heard, and if the light is extinguished the sounds continue to be audible even after the disc ceases to be visible in the darkness. The experiment can be made without difficulty with receivers of glass or mica, thin and smoked so as to have a true thermophone.—*Comptes Rendus.* C.

Thermal Conductivity of Fluids.—H. F. Weber has experimented upon the thermal conductivity of water, glycerine, alcohol, ether, chloroform, benzine, olive oil, citron oil and various solutions, and he finds that transparent, non-metallic fluids have nearly equal conductive power at equal temperatures.—*Wiedem. Ann.* C.

Dressing for Leather.—A fine, brilliant, elastic dressing for leather, which does not injure shoes, can be made as follows: To three pounds of boiling water add, with continnual stirring, a half pound of white wax, an ounce of transparent glue, two ounces of gum senegal, one and a half ounces white soap, and two ounces of brown candy. Finally, add two and a half ounces of alcohol, and, after the whole is cooled, three ounces of fine Frankfort black. The dressing is thinly applied to the leather with a soft brush and after it is dried it is rubbed with a piece of fine pumice stone and polished with a stiff brush.—*Badische Gewerbe-Zeitung.* C.

Accurate Thermometers.—A. Wüllner has been making new investigations of the specific heat of water, and he has found additional reasons for insisting upon the importance of careful thermometric graduation. The customary method of fixing the freezing and boiling points, and dividing the interval regularly, is very inaccurate, and in many of the modern delicate physical investigations it leads to results which are wholly untrustworthy. He asserts that no quicksilver thermometer should be used in physical measurements which has not been carefully graduated throughout the entire length of its scale by comparison with an accurate air thermometer.—*Wiedemann's Annalen.* C.

Artificial Soil.—M. Dudouy, of Saint Ouen, has been very successful in chemical horticulture. In his garden he has cultivated legumes, flowers and trees in parallel rows in three manners: 1. with ordinary manure; 2. with chemical manures in garden soil; 3. with a special compound, which he calls *floral*, in pure sand. The results of the third experiments have been very striking, yielding the earliest, the largest and the most delicate vegetables, as well as the most thrifty and brilliant flowers. The *floral* contains nitrogen, phosphoric acid, potash, magnesia and sulphur in a form so concentrated as to require dilution with twenty thousand times their volume of water. The experiments have been continued for five years with uniform success. —*Les Mondes.* C.

Bursting Power of Ice.—Ed. Hagenbach experimented, during the past severe winter, upon the bursting force exerted in the expansion of water when freezing. Two interesting experiments were made with cast-iron hand grenades. The outer diameter was 15 centimetres (5·9 in.), the inner diameter 12·8 cm. (5·04 in.) The shells were filled with water, closed with a screwed iron plug, and exposed to the cold. Both shells were broken, and a curved thread of ice was projected, by means of an ice column, from the upper surface. One of the plugs was evidently thrown out with great violence, and to such a distance that it could not be found. The curvature in that case was bent upward.—*Wiedemann's Annalen.* C.

Comparative Value of Steam Engines.—Hallauer's recent experiments have led him to the conclusion that the difference between engines of one and two cylinders, in point of economy, is very slight. In ranging from 80 to 8000 horse-power, with revolutions varying from 25 to 90 per minute, the expenditure of steam for a given amount of work remains the same for the same type of motor; the consumptions for two cylinder motors are identical for Woolf and compound, whatever may be the volumes of the cylinders, provided the motors are regulated so as to give the maximum efficiency; the expenditures of steam in motors of one, two and three cylinders, suitably regulated and constructed, are so nearly alike that the choice may be governed in each instance merely by the fitness of the type of the engine for the particular purpose desired.—*Bull. de la Soc. Ind. de Mulhouse.* C.

Franklin Institute.

Hall of the Institute, May 18th, 1881.

The stated meeting was called to order at 8 o'clock P.M., the President, Mr. William P. Tatham, in the chair.

There were present 58 members and 9 visitors.

The minutes of the last meeting were read and approved.

The Actuary presented the minutes of the Board of Managers, and announced that at their last meeting 13 persons were elected members of the Institute.

Mr. Cartwright asked and obtained unanimous consent for a suspension of the order of business, to take up the consideration of the

repeal of section 4 of Article III of the By-laws, as recommended by the Board of Managers; also, to alter section 1 of Article I to read as follows:

"The real and personal estates of the Institute, as held upon the 1st day of January, 1881, shall be valued at one hundred thousand dollars, and shall be represented by ten thousand shares of stock of the par value of ten dollars each; and in addition thereto, all sums of money or other property contributed to the Trustees of the Building Fund, for the purposes of the Institute, shall be represented by an additional number of shares of stock, of the same par value of ten dollars each, which may be issued by authority of the Board of Managers."

Upon motion, the Secretary was directed to make the necessary publication of the above.

The following donations to the Library are reported:

Transactions Pennsylvania State Agricultural Society for 1871–2; 1874–5; 1878–1880. From the Society.

Transactions from the Wisconsin State Agricultural Society for 1874–5; 1876–7; 1879–80. From the Society.

Transactions of the Illinois State Agricultural Society for 1859–60; 1872; 1874; 1876; 1877, and 1879.
From the Department of Agriculture.

Annual Report of Operations of the United States Life-saving Service for year ending June 30, 1880.
From the Life-saving Bureau.

Minutes of Proceedings of Institution of Civil Engineers. Vol. 63. London. 1880–1881. From the Institution.

Report of the Board of School Commissioners of Baltimore for 1880. From the Commissioners.

Papers Relating to the Foreign Relations of the United States. 1880. From the Department of State.

Memorial of Joseph Henry.
Smithsonian Contributions to Knowledge. Vol. 23.
Smithsonian Miscellaneous Collections. Vols. 18—21.
From Smithsonian Institution.

Official Army Register for 1881.
From Adjutant-General U. S. A., Washington.

On the Ventilation of Halls of Audience. By Robert Briggs, C.E. Philadelphia. From the Author.

Ninth Annual Report of the Board of Directors of the Zoölogical Society of Philadelphia. 1881. From the Society.

Useful Information Pertaining to the Generation and Use of Steam. From Babcock & Wilcox, N. Y.

Preliminary Report upon the Iron and Steel Industries of the United States. By James M. Swank. From the Author.

Almanaque Nautico para 1881 and 1882.
From Observatory of the Maritime Institute, San Fernando, Spain.

Proceedings American Academy of Arts and Sciences. Vols. 1—8. 1846–1873; New Series, Vols. 1—8 (Part 1) 1873–1881.
From the Academy.

Dr. Robert Grimshaw read an interesting paper on "Air Compressors," and a number of photographs of various machines were projected upon the screen. An abstract of his paper is here appended:

"Air under pressure is employed for the transmission of power, as the principal or auxiliary of various industries, in mines, in quarries, well driving, building bridge piers, in tunneling, in the production of cold, in sugar-making and refining, and various chemical works, the manufacture of iron and steel, for ventilating mines or buildings, for transmitting letters or packages in pipes placed underground or otherwise, in driving street cars, etc. It makes no dirt, and liberates no offensive gases. For the transmission of power it has the advantages over steam that it can be carried for any distance without losing any power by condensation or cooling; it is drier and cooler than steam; and in mines and tunnels, instead of rotting timbers and heating the galleries, it gives good forced ventilation by good, pure cool air. It can be applied in any direction and around corners; and, by the use of flexible pipes, may be moved as the work changes; it may be used economically and applied with little loss from friction. As an instance of this last, I may state that in the Hoosac tunnel air was carried 7150 feet in 8-in. iron pipes, its pressure falling from 67 pounds only 2 pounds. It is my intention, this evening, to narrate briefly the gradual march of air compression as a factor in the industries, and to show the principal types of modern compressors.

"Ctesibus discovered that air was compressible, and his pupil, Hero, of Alexandria, wrote a book to prove it; but from that time till Papin's date but little was heard of it. Papin proposed its use for running engines. In 1726, Rowe, in an English patent, proposed

raising water by compressed air; and, in 1753, Hall, at Schemnitz, raised water 116 feet thereby. In 1757, Wilkinson, in a British patent, suggested its use for blowing furnaces, with a series of vessels and a column of water to effect the compression. (It may be noted that the modern tendency in air compression is the use of water as the compressing medium.) In 1810, the elder Brunel, in a patent bearing his name, was vainly endeavoring to patent perpetual motion.

"In 1828, Bompas, in a provisional British patent, proposed to propel locomotives by compressed air; and, in the same year, Colladon proposed to Brunel to employ it in the Thames tunnel.

"In 1829, Mann proposed to propel fixed and locomotive machinery by air compressed in a series of pumps of successively smaller areas, calculating these areas up to the sizes needed to 64 atmospheres pressure. It must be noted that this is the origin of what is known as 'stage-pumping.'

"In 1836, the receiver, as an appendage to the compressing parts, appears; and, in 1841, Von Rathen again suggested compressed air for driving locomotives. In 1844, Coligny brings the hydraulic ram into play for air compressing; and, in the same year, Parsey patents its application for propelling carriages.

"In 1847, Von Rathen introduces the use of water for the purpose of absorbing the heat of compression. In 1852, Colladon patents its application for driving machine drills in tunnels, at present one of its most important applications.

"In 1853, Sommeiller invented hydraulic compression, or rather the use of large moving bodies of water as an adjunct to a suitable traveling piston.

"In 1853 also, Anderson patented the injection of cold water into the cylinder of the compressing pump.

"In the same year, Piatti proposed compressed air as a motive force for rock drills in the Mont Cenis tunnel; and, the year following, Parsey made the important step of putting the valves in the end of the cylinder. In 1861, rock drills, driven by compressed air, were at work in the Mont Cenis tunnel.

"In 1863, Stewart & Kershaw made a horizontal cylinder filled with water and attached to two upright air vessels, in which, alternately, the air was compressed.

"In 1864, Coughlin brings out stage-pumping, with intermediate air-vessels to give regularity of pressure; but strangely enough seems

not to have seen the still greater advantage these intermediate air-vessels would give in cooling the compressed fluid.

"In 1866, air compressors were at work in our own Hoosac tunnel, horizontal pumps being employed. In the next year, vertical pumps were substituted.

"In 1867, Doane, in this country, constructed a horizontal single-acting crank compressor, placing inlet valves in the piston-head, the discharge valves occupying the whole space across the cylinder-head, and being closed by a spring.

"In 1869, Marchant proposed to use compressed air with water for the purpose of making steam and to reheat the air, with some wild idea of increasing power.

"In 1873, Sturgeon brought out a high-speed compressor with steam and air cylinders, one each side of a receiver, and having a crank shaft with a fly-wheel; the cranks being quartered, in order that the greatest pressure of the steam may be exerted at the time of the greatest resistance of the air in the cylinder.

"In 1874, William Johnston, now of our own city, proposed a series of concentric cylinders revolving upon a fixed axis and having the lower halves filled with water, the face of which served as the bottom of the pump; and in this machine, as in the later modifications thereof, stage pumping was employed.

"In the earliest Burleigh compressor the cranks were quartered and the air cylinder vertical, in order that the valves might shut by their own weight. Cooling is effected by a water jet; the valves were circular plates; the steam piston, at first horizontal, is made vertical, and now the air cylinders are closed at the bottom and a more economical type of engine employed.

"Compressors are known as either wet or dry, according as water is or is not employed in the cylinder for lubricating and cooling. Dry compressors had at first the disadvantage that the valve could not be kept tight, and that the valve stems broke from constant slamming. These troubles are now avoided by the employment of rubber discs for valve faces and cushions.

"The well-known Dubois-François type of compressor is horizontal and employs a large body of water set in motion by a reciprocating piston, there being a large inclined inlet flap valve at each end of the cylinder and a large vertical poppet valve, for discharge, above each end.

"The Ingersoll compressor, as now made, is vertical and with cross-heads and guides and adjustable cut-off engine, this last feature increasing its capacity 20 per cent. and saving 25 per cent. of fuel. The crank is forged of iron. This compressor has one steam and one double-acting air cylinder, horizontal and side by side (each cylinder having its own bed) and the two rigidly bolted together. The inlet air valve has a slide valve closed with springs and moved by an eccentric on the main shaft and is balanced by letting the pressure from the discharge pipe into the valve box; the valves are discharge poppets arranged upon the top of the cylinder upon each end.

"In the Clayton long-stroke duplex compressor there is a water jacket completely encircling the ends first and discharging at the top, the objects being to cool the cylinders most where they are most heated and to insure the jackets always being full. The discharge valves are lifted by adjustable drop, letting the air escape as soon as it has reached the working pressure, instead of further compressing it. The cylinder is supplied with water or lubricant at each stroke, and only when working. The yoke is constructed so that the wear can be taken up in the block and in the slides at the same time. There is an air governor which keeps the pressure regular. The suction valves opening into the air cylinders have safety stems, preventing the valve from falling into the cylinder, or other accidents, if the stem breaks or the nut comes off.

"In the new Rand horizontal dry compressor the steam cylinder has poppet valves and variable automatic cut-off; the cylinders are side by side, bolted to the same bed plate; crank quartered. There is water circulation through piston and cylinder heads and around the cylinder, the cylinder having three shells, forming two annular spaces around the working cylinder. The outer space is for the air after compression, and the middle one for water circulation. The air tank receives air at one end and the discharge is through a safety valve at the other.

"In the Norwalk high speed compressor air is always taken from the outside of the engine room, to insure its being cool; increase of capacity and economy of fuel being claimed for this. The valves are drop forged; the oil cup drops oil through a wick, under pressure; combined air cylinders are employed, there being a pipe cooler between the cylinders; there is an air governor and an attachment for charging

mine locomotives, etc., by which an auxiliary compressor is thrown into action when desired. The low pressure cylinder will have say 100 square inches of area, and the high pressure 33⅓, and the air crowded from the large into the small cylinder becomes compressed to 30 pounds per square inch, the resistance being 66⅔ times 30, equal 1999 pounds, and ends at 100, the resistance being 33⅓ times 100, equal 3333, at the same time there being a compression, as before, with 1999 pounds work done, or a total of 5333, instead of 10,000, as would be the case with the single large cylinder. By having all on one heavy cross head, the momentum stored up is given out when the the steam gets weak. The air discharge valves in a single cylinder compressor have the full receiver pressure more than half of each revolution. In the compound the heavy pressure is upon small valves only. To lessen the effect of clearance there are two ways of doing; the stroke may be made long and the piston run close, which is expensive, and requires careful watching or the space may be filled with water, which prevents high speed, as the water gets churned to a foam, besides making ice in the exhaust of the drills or other machine using the air. The water jacket has not time to fully cool the air, even if it were not rapidly covered by the advancing piston; but it is a valuable auxiliary.

"In the patent granted to Mr. W. P. Tatham, the President of this Institute, there is a steam and an air piston, each reciprocating in a cylinder, and a double armed rock shaft, connected with the steam and air piston rods, these members being combined for joint operations to compress air under a decreasing leverage of the air piston arm, and a correspondingly increasing leverage of the steam piston arm.

"In the indicator card of an air cylinder shown, the discharge valves are lifted automatically, but there is a heavy loss caused by the absence of water from the cylinder as the compressed air not discharged at the end of the stroke follows the piston back about one-fifth of the stroke. The card of the steam end of the Clayton compressor is taken at 90 revolutions, 70 pounds boiler pressure cutting off at 52 per cent., and giving an air pressure of 100 pounds.

"As far as possible, a good compressor should be simple in construction, have large valve area, be light running, compress at low temperature, have little wear and tear of working parts, be cheap in first cost, economical in use of steam or other power and of cooling water; be compact, need light foundations and be free from breakage.

It is in most cases well that the lines of motion should be the seam and the clearance space small."

Mr. Henry M. Knapp made some remarks on "Engineering Errors on Rivers and Harbors," illustrated by maps and diagrams. The subject gave rise to considerable discussion, in which Messrs. Nystrom, Cartwright and Bilgram took part.

The Secretary's report included an account of Chief Engineer Abel's Water Gauge for Marine Boilers. As a vessel at sea does not always remain on an even keel, the ordinary water gauge does not show accurately the height of water in the boilers, and this has to be estimated by the "water tender." In his anxiety to keep sufficient water over the outboard heating surface he is very apt to carry the water too high, thus causing the boilers to foam and carry water over into the cylinders of the engines. To give the water tender a true guide to the height of water in the boiler when the ship has heeled over, Engineer Abel provides the boiler with the ordinary glass water gauge, and also with a reservoir of glycerine connected with a tube of much smaller diameter set near the water gauge. The reservoir is filled with glycerine or other suitable fluid to the height it is desired to keep the water over the highest heating surface. When the ship heels over the reservoir is carried up with the boilers on the weather side. The area of the cross-section of the reservoir being so much greater than that of its tube extension, the level of the fluid in the reservoir will remain practically constant at the highest heating surface, while the height of the liquid in the tube, being on a level therewith, will furnish a guide for the height of water to be maintained in the glass water-gauge. The device is simple, and can be applied to boilers furnished with the ordinary gauges.

Mr. Wm. S. Auchincloss exhibited a curious averaging machine, or book-keeper's assistant. It was designed for use in averaging dates of purchase of spools of cotton, but can be applied to many other purposes. It consists of a grooved platform, balanced by a scale beam and pan. The weights bear to each other the ratio of one to ten and one to one hundred. There are thirty-one grooves in the platform, representing days of the months, and thirty-one corresponding divisions on the scale beam. Weights representing the amount of the purchases are put in the grooves corresponding to the dates of purchase. An exactly equal load is put in the pan, and the latter is then shifted along the scale until the two parts of the apparatus are in

equilibrium. The date from which the pan is suspended gives the *average* date to which the purchases of the month should be charged. The inventor claims that a man with very little knowledge of accounts can with this apparatus average one hundred accounts per hour. The machine can be employed also to determine many other problems in proportion.

V. Quarré & Co. exhibited Hink's duplex lamps, which have a double or two entirely separate flames, fed from one reservoir of oil. They are said to give a light of twenty-six candles, burning one quart of oil in ten hours. They have a mechanical device for extinguishing the light without blowing it out.

Theodore Bergner exhibited a very conveniently arranged upright drawing board and stand, to be used in making large mechanical or architectural drawings. The board is suspended in a nearly vertical position, and is easily adjusted. It is provided with a blade or ruler, in place of a T square, guided in its absolutely parallel movement by simple mechanism, and also with facilities for taking and transferring measures and for keeping all required instruments within easy reach of the draughtsman.

Dr. Grimshaw explained a valve from a Wheelock engine, which showed very little wear, although it was said to have been in use for six years.

Mr. Washington Jones said that the valve was almost precisely like one that was put in the steamer *Adriatic* some time ago, and proved a complete failure.

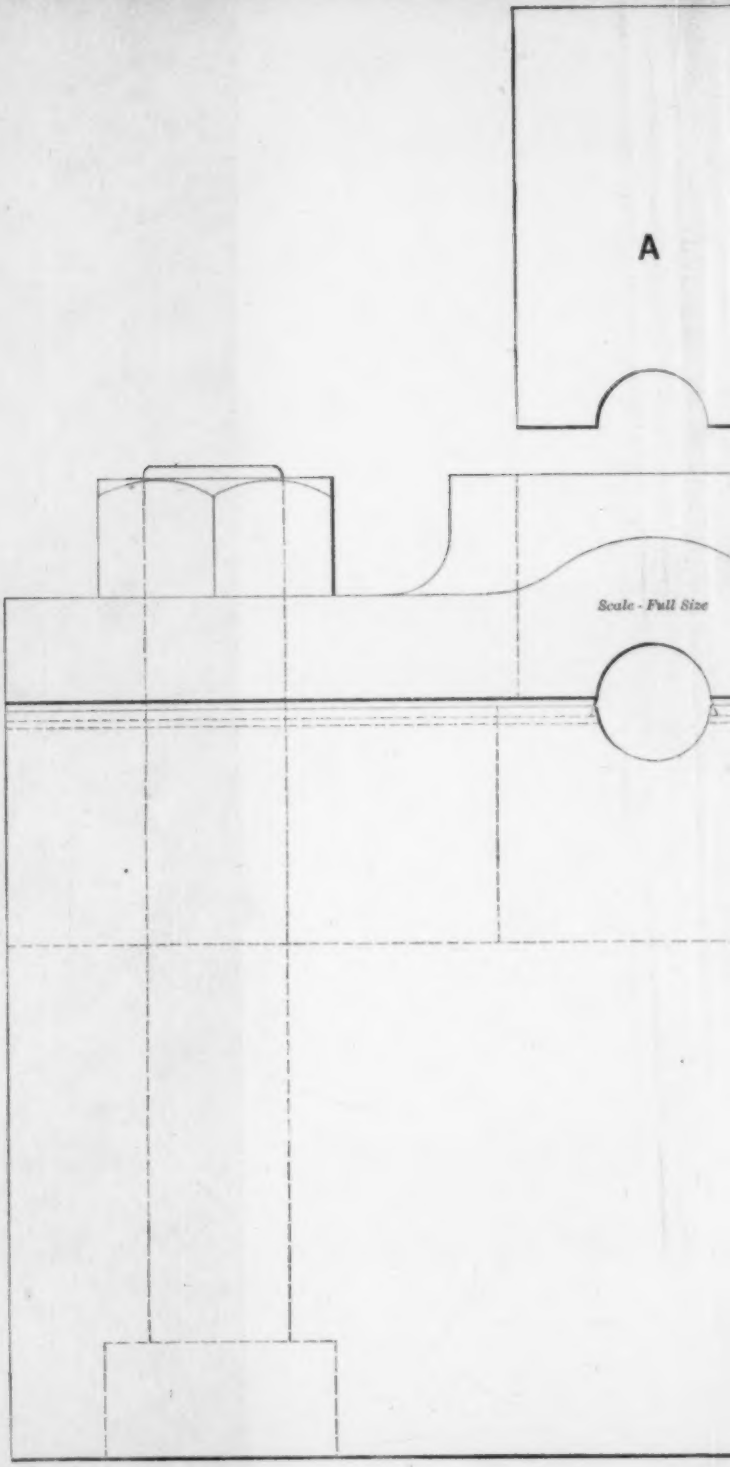
Dr. Grimshaw said he knew nothing of the *Adriatic* valve. As regards the wear of the Wheelock valve, it and the worn Corliss valve accompanying it were sent to the Institute by Mr. Wheelock, with the endorsement from the Lowell Manufacturing Company.

Mr. Bilgram exhibited an ingenious little machine for making wire staples to serve as loops for hanging up pamphlets. The wire is brought together in loop form, the two ends are twisted together and bent into shape in one revolution of the driving wheel, seven operations being performed by four cams at the rate of sixty staples per minute.

The President then announced the Committee to solicit Subscriptions for the Building Fund.

There being no further business, the Institute adjourned.

ISAAC NORRIS, M.D., *Secretary.*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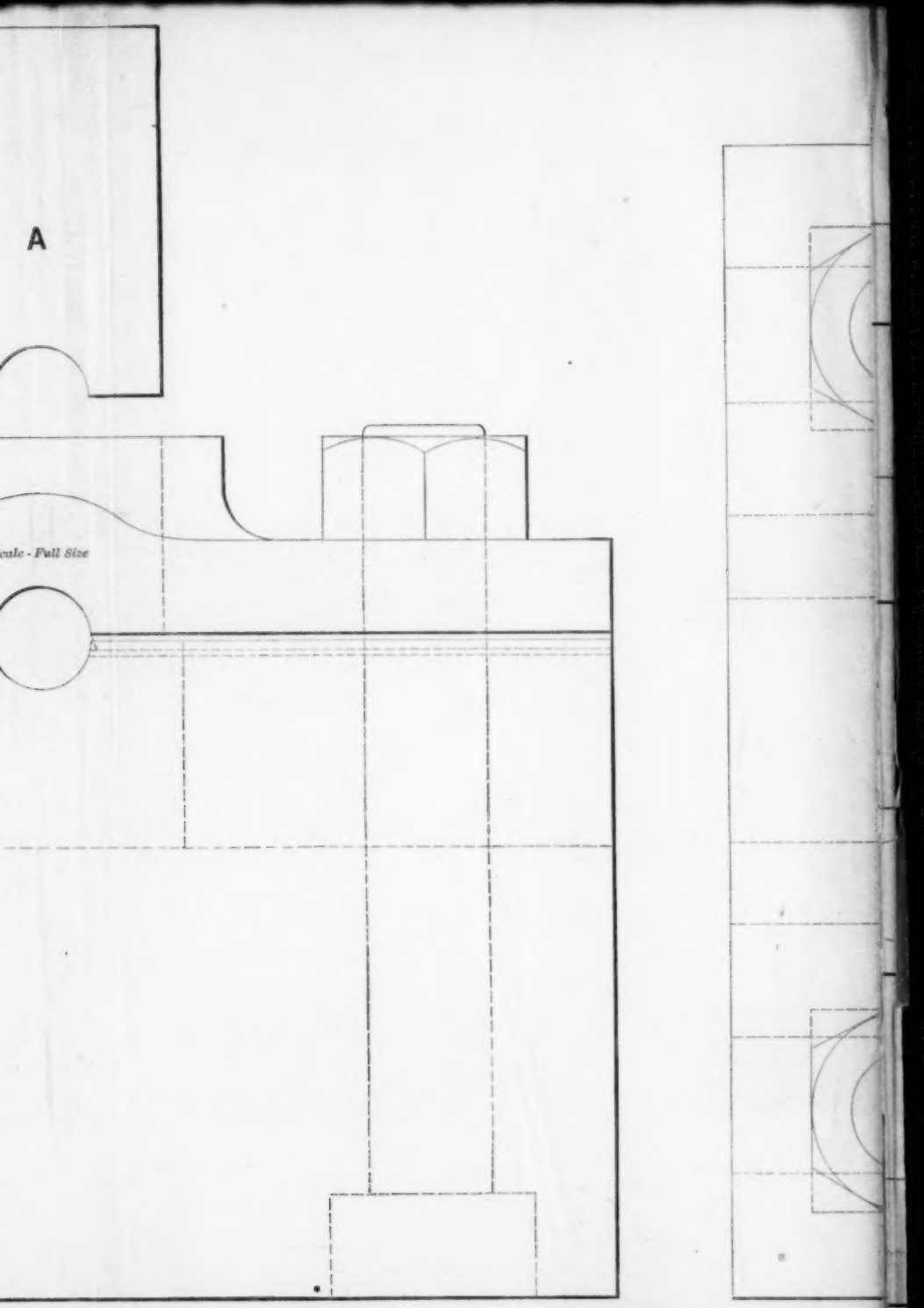
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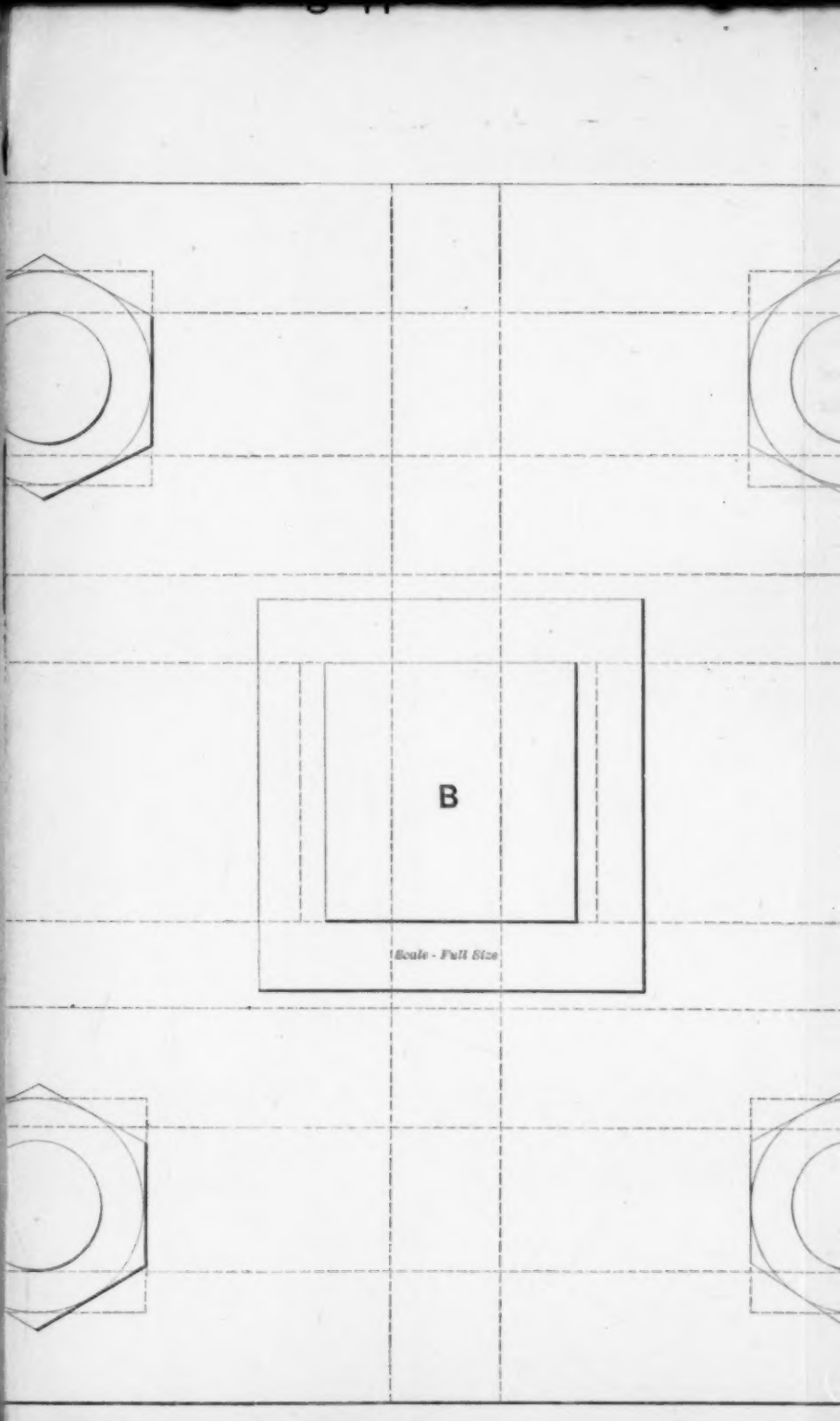
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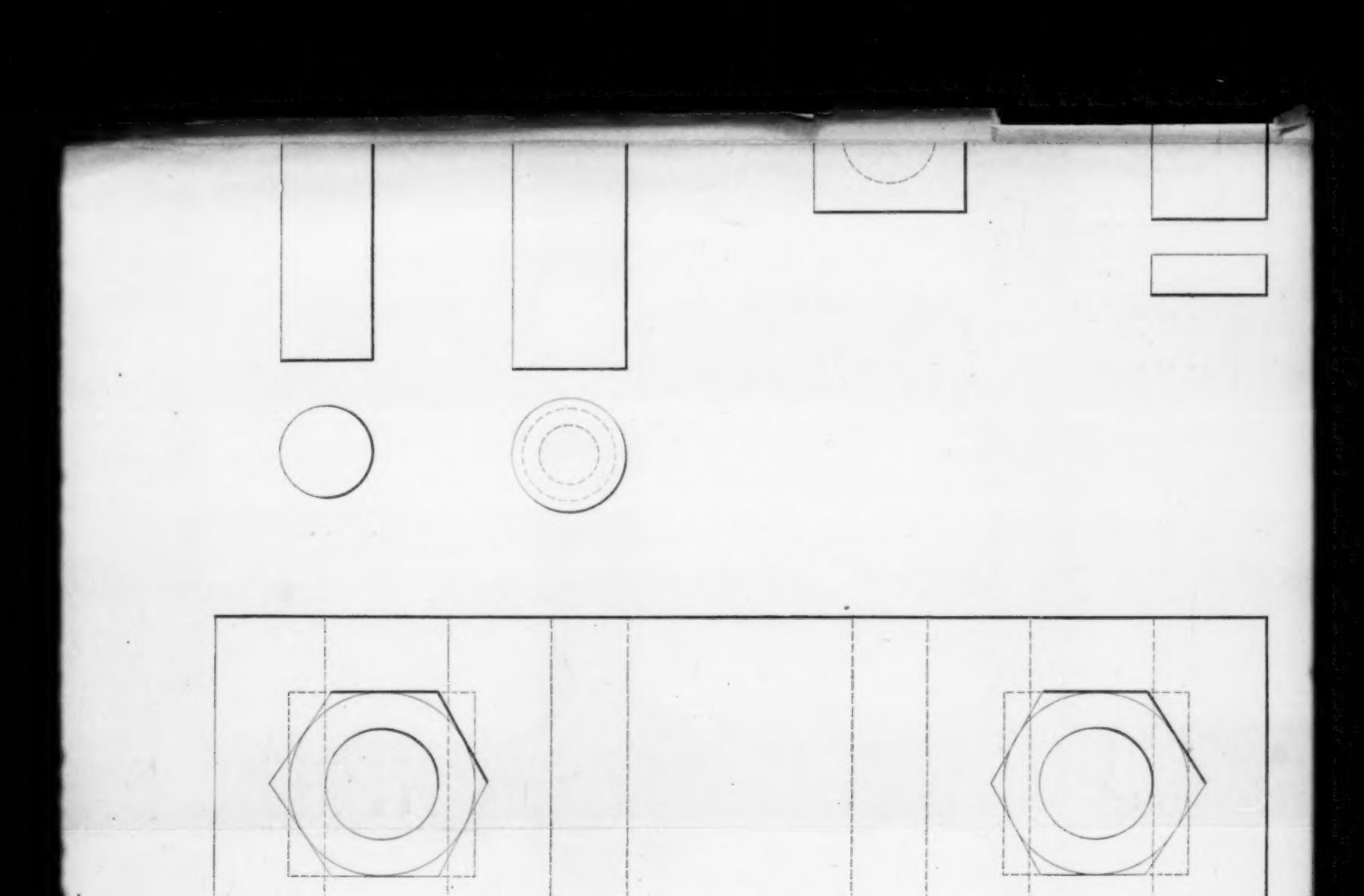

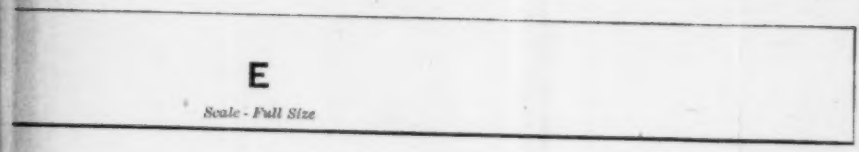
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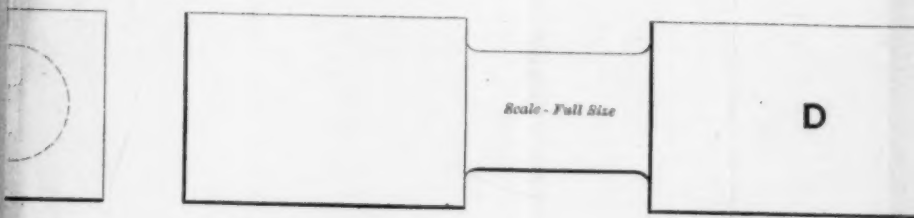
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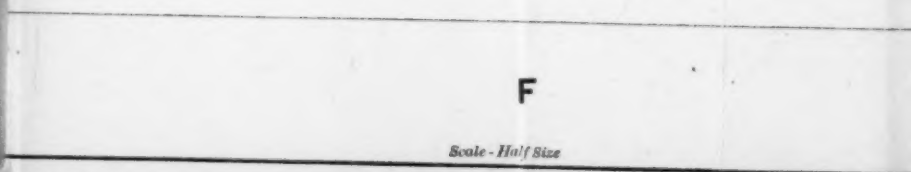
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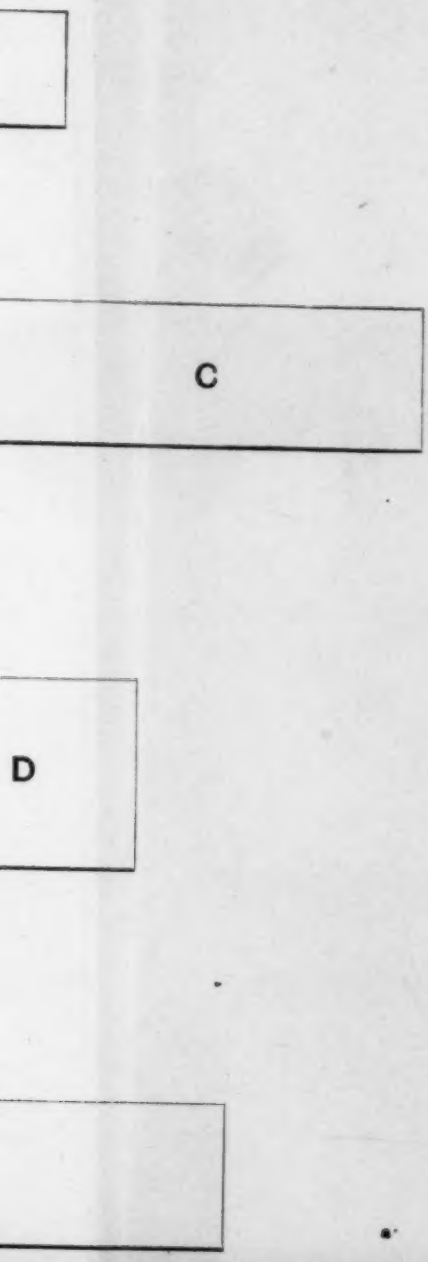
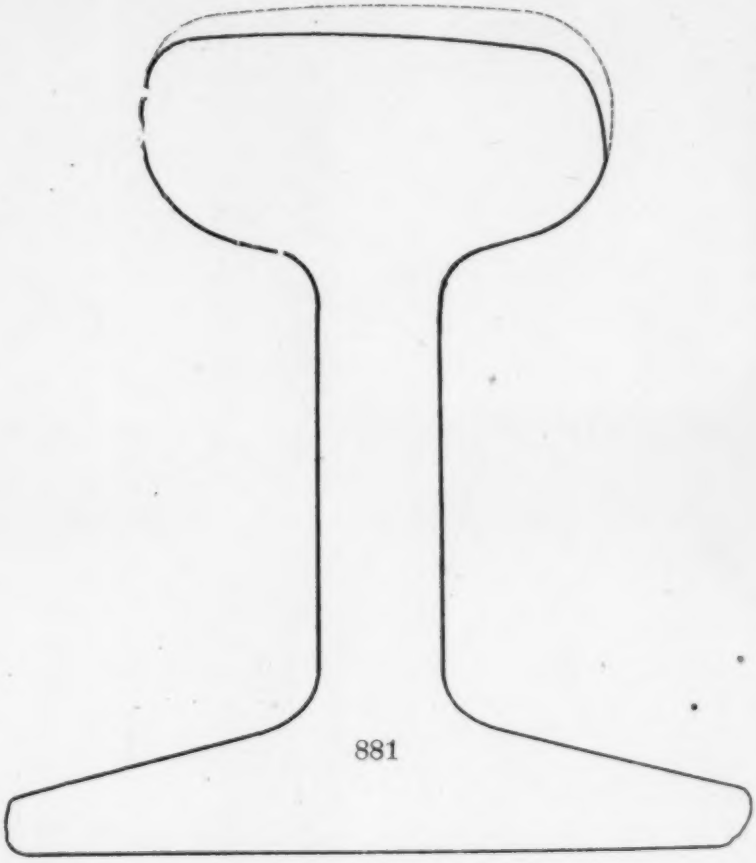
Plate I.





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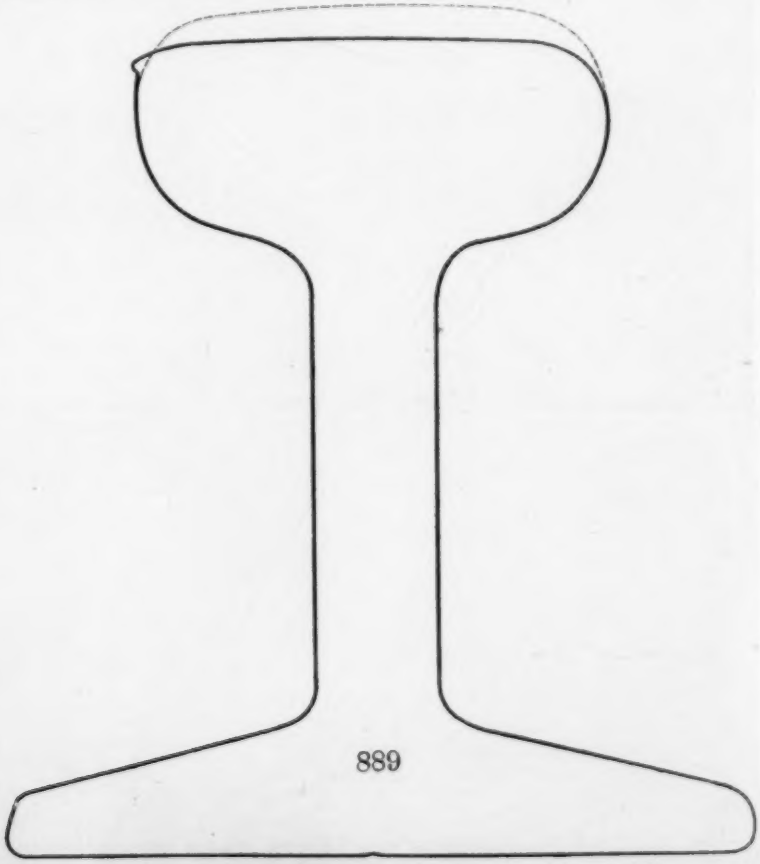

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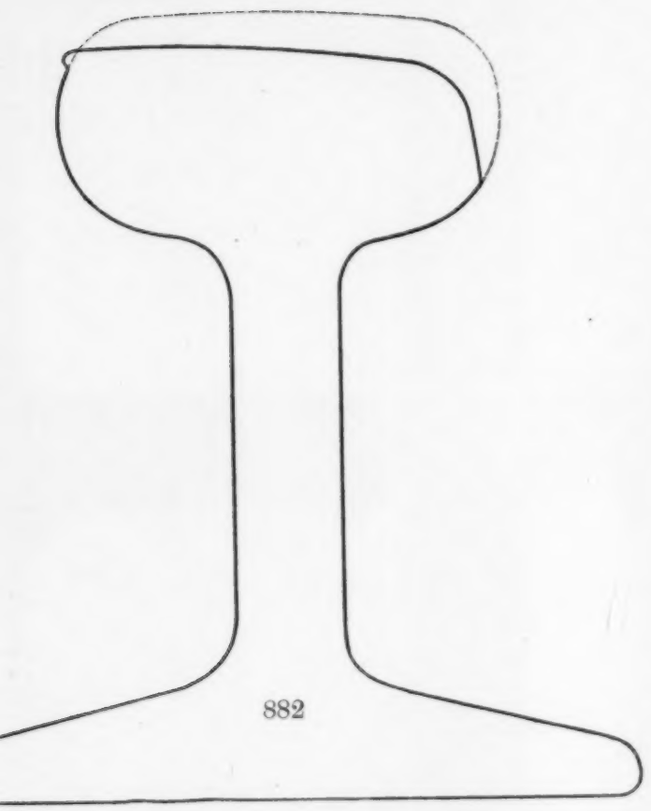

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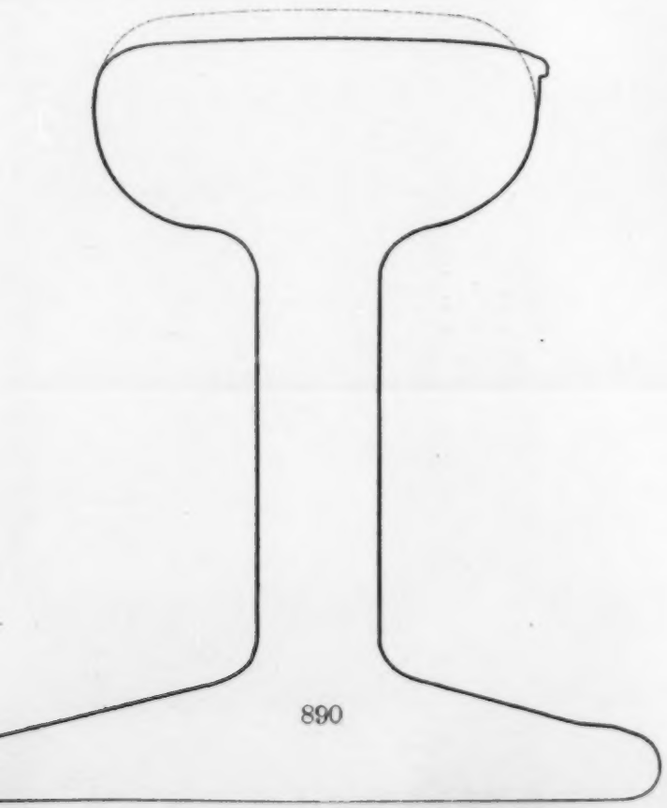

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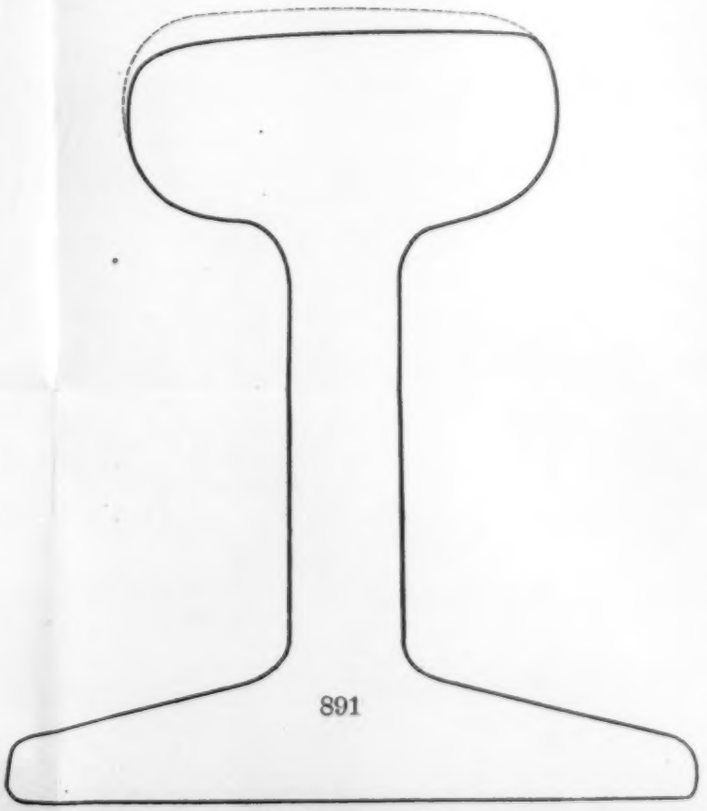

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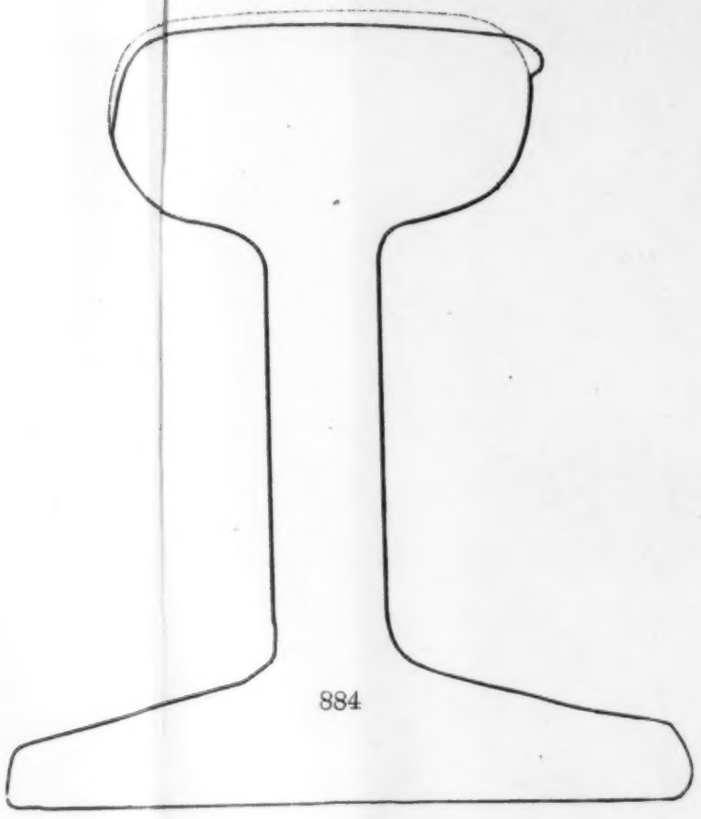
Diagrams of Rails on Grade Tangents.



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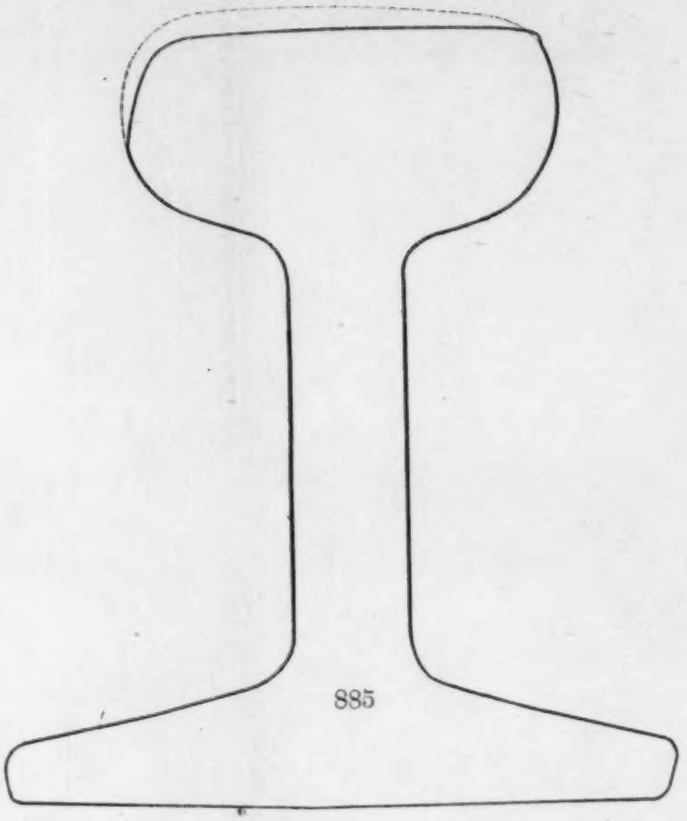

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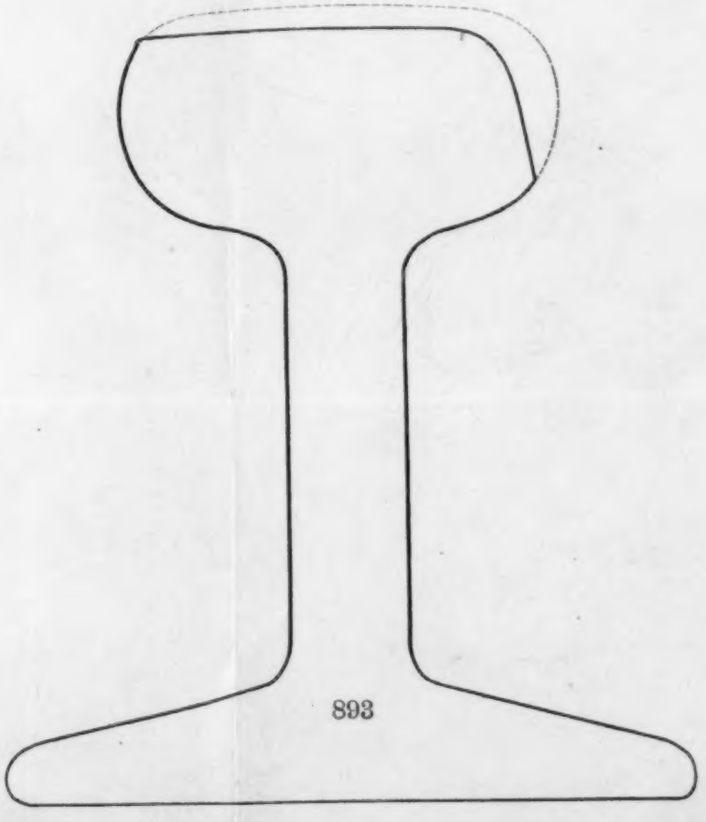

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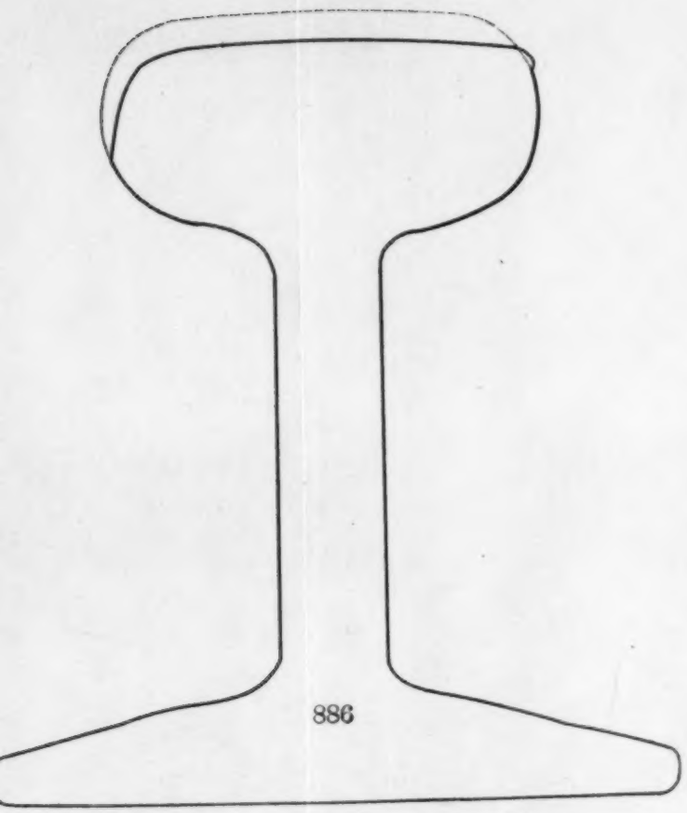

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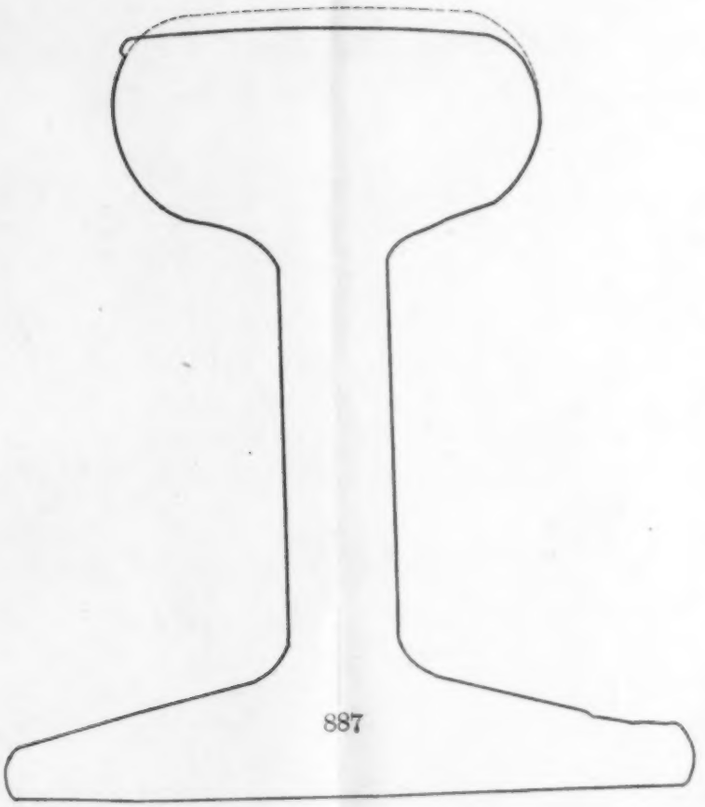

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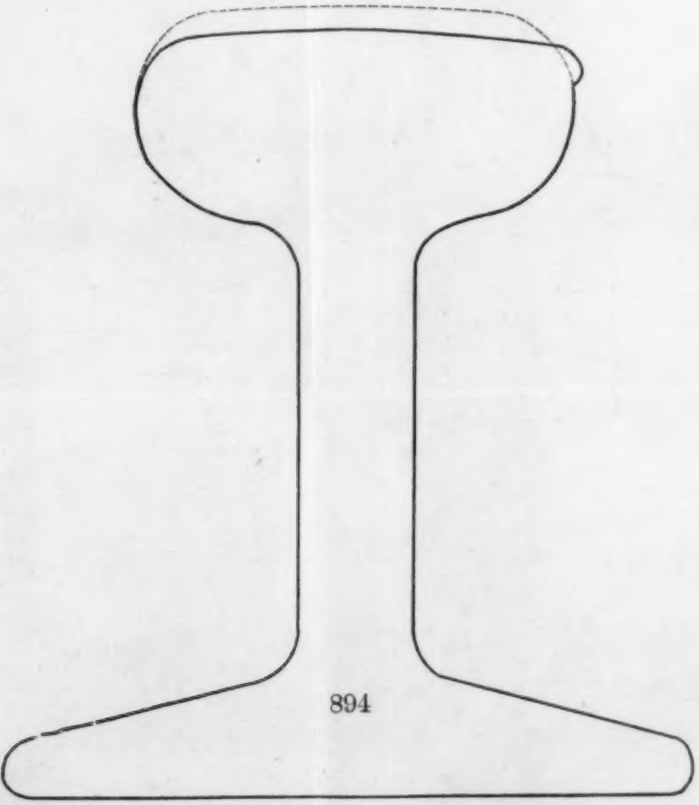

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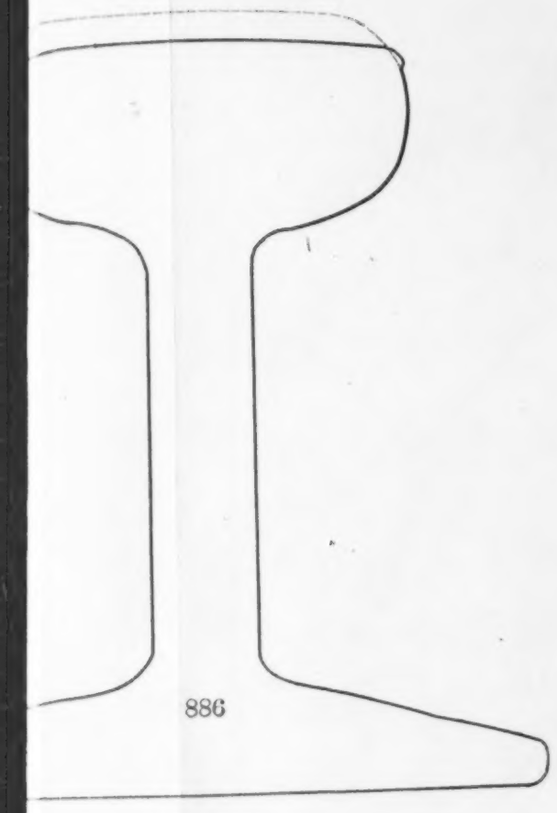

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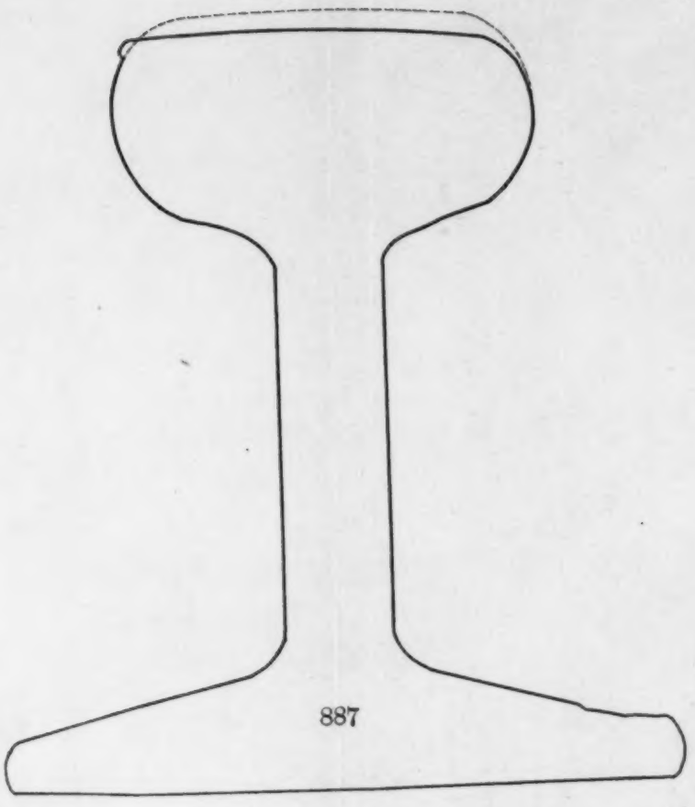

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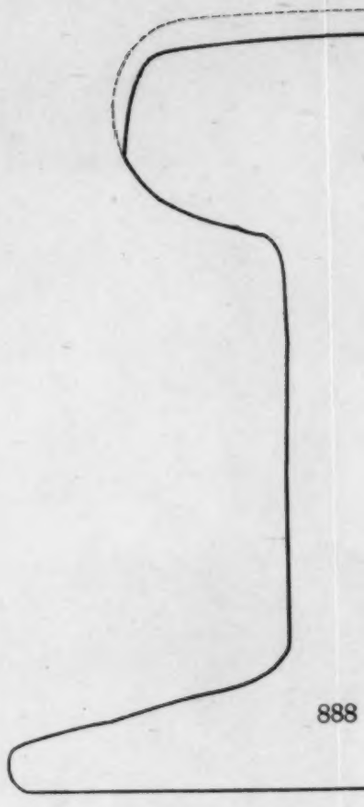

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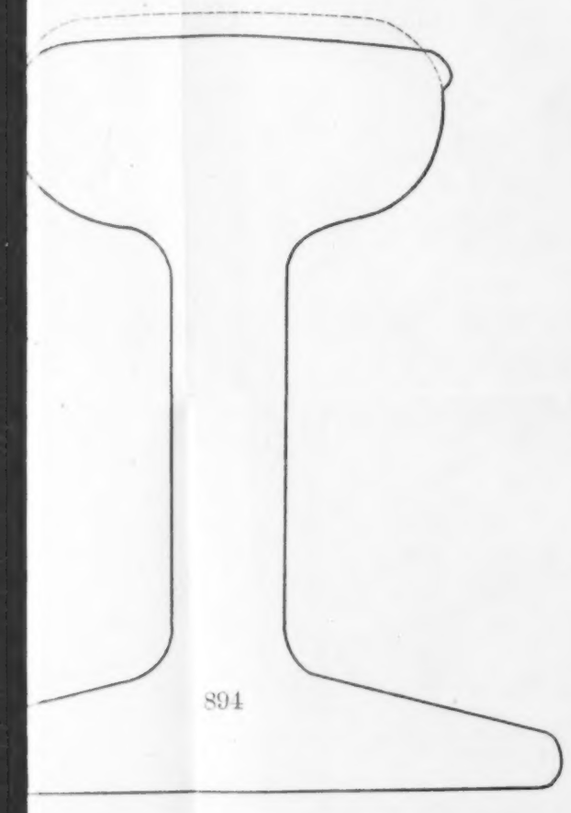

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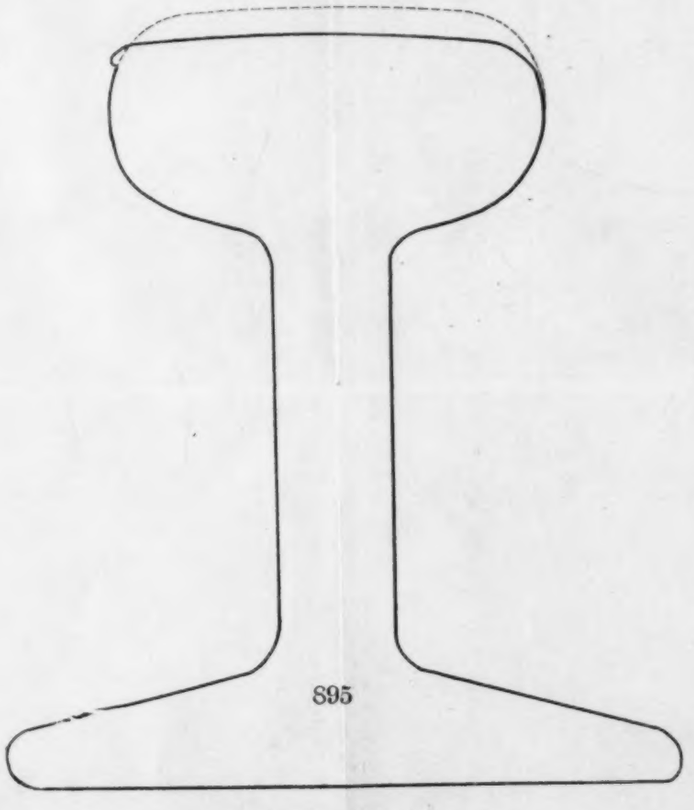

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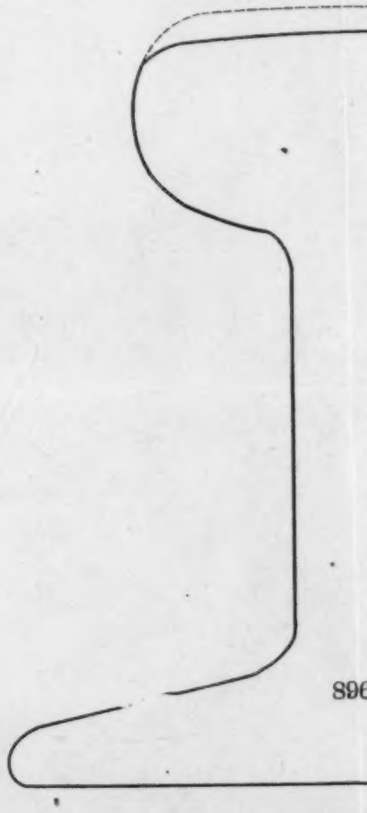

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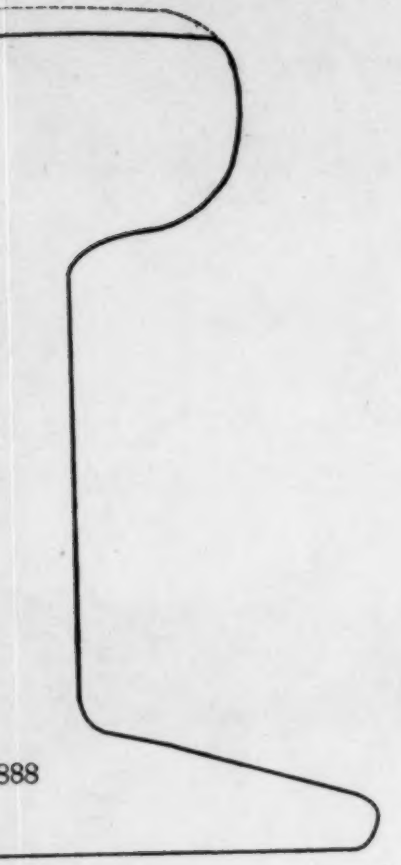

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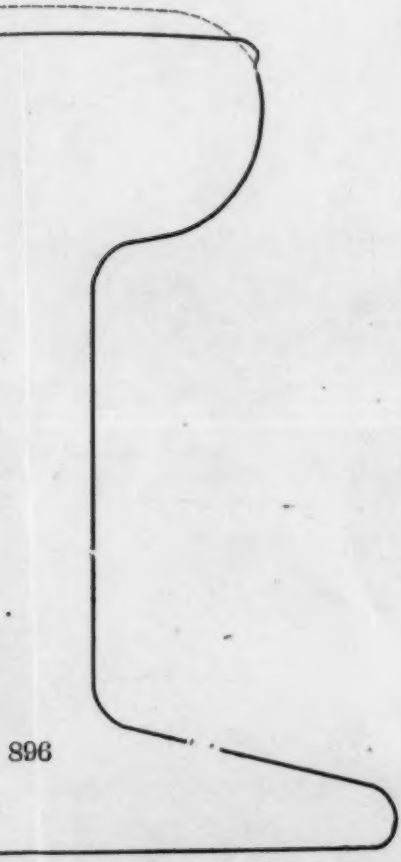

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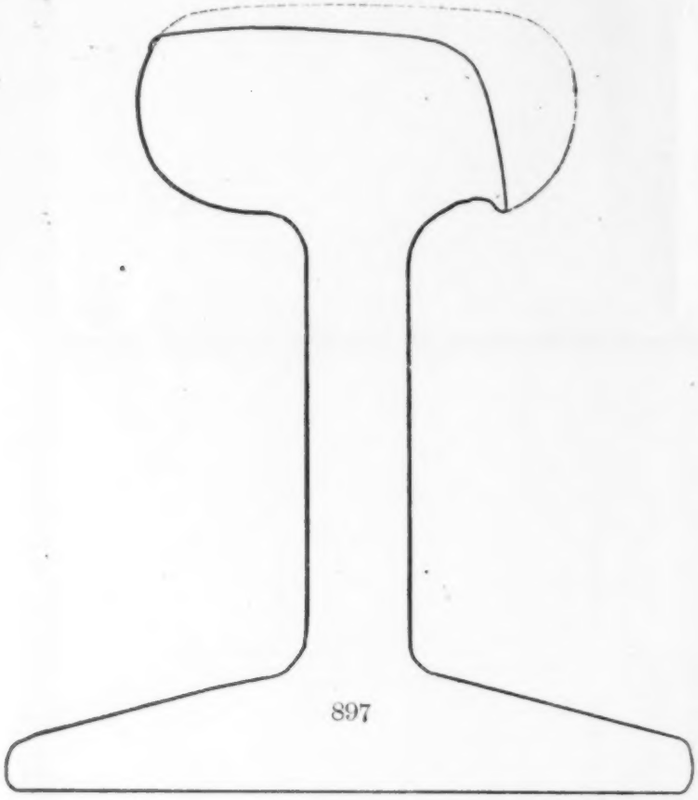

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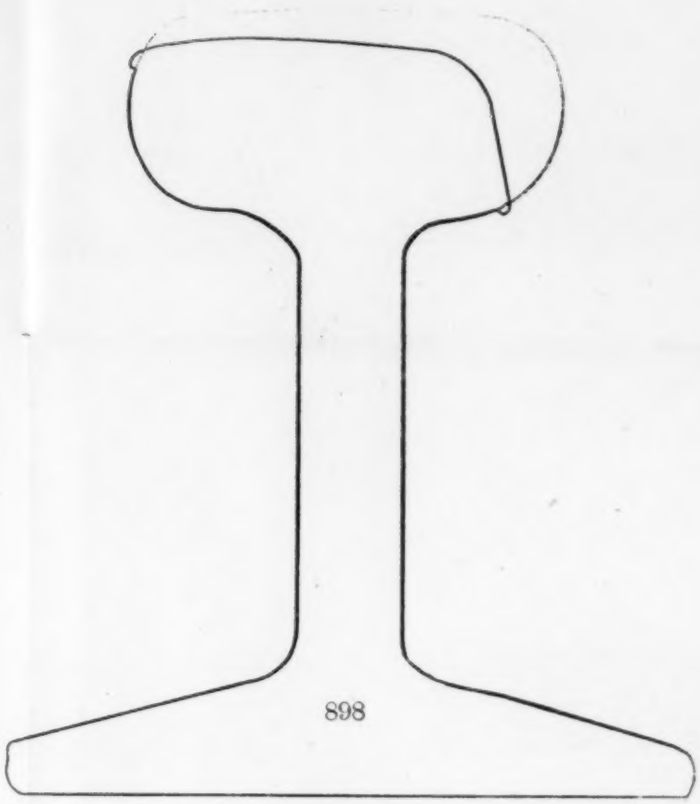

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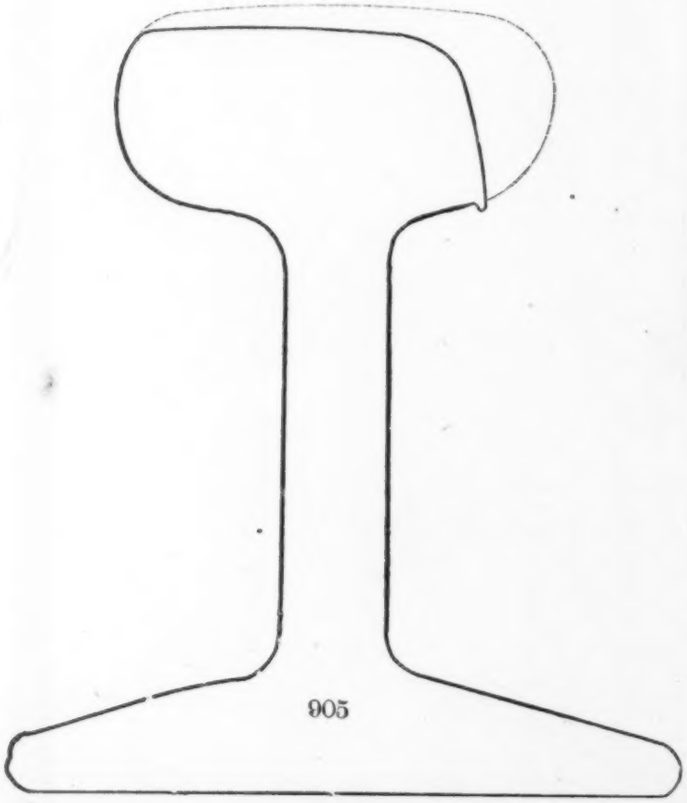

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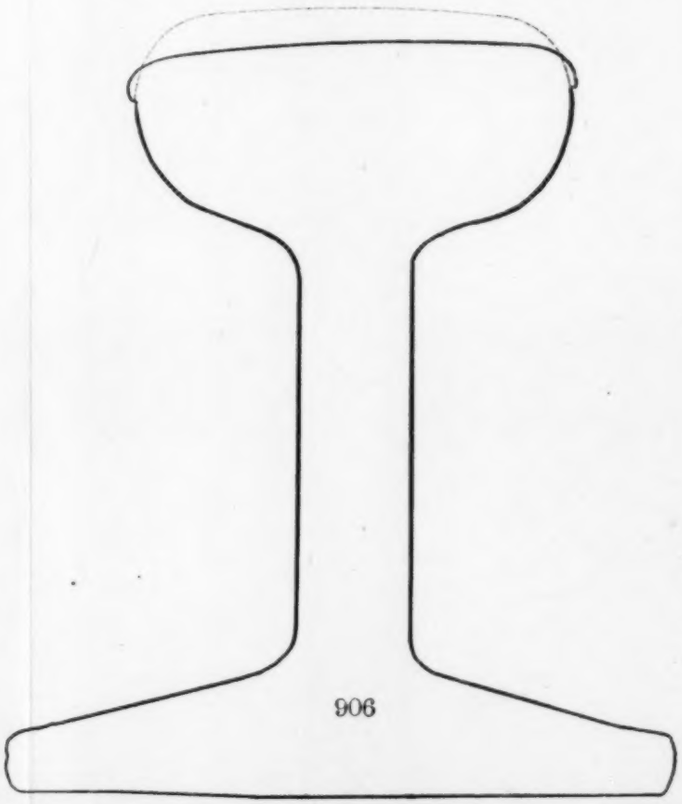

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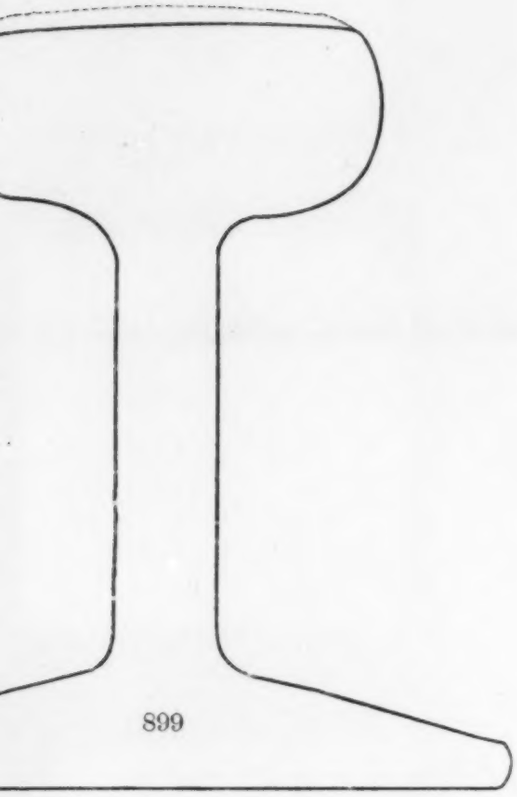

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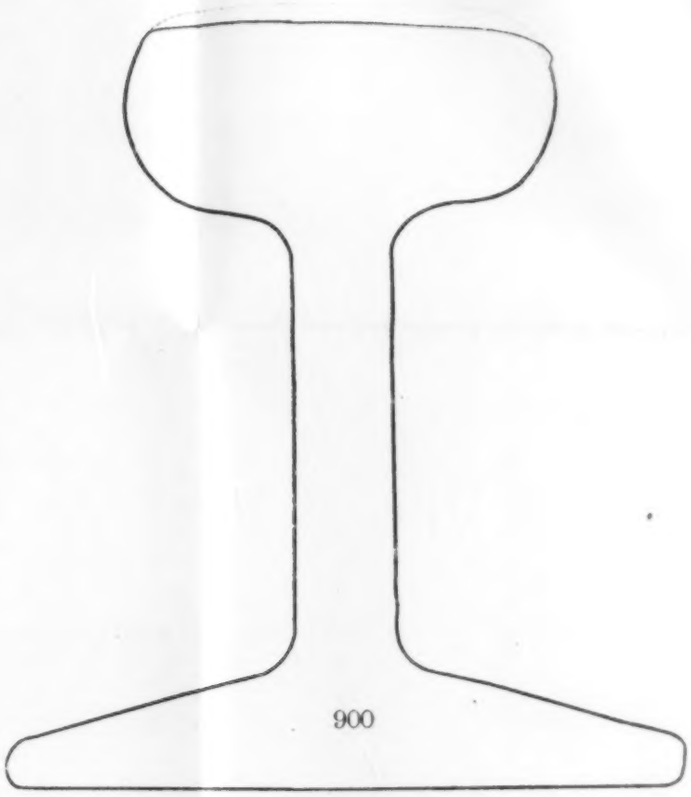

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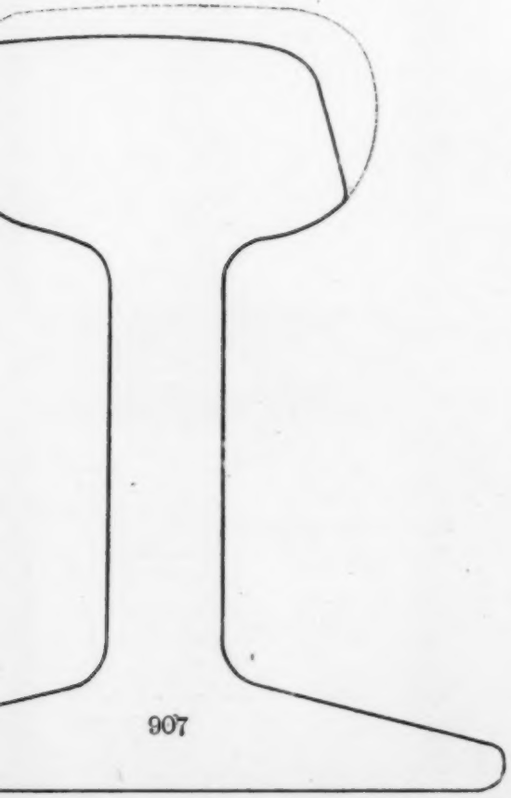

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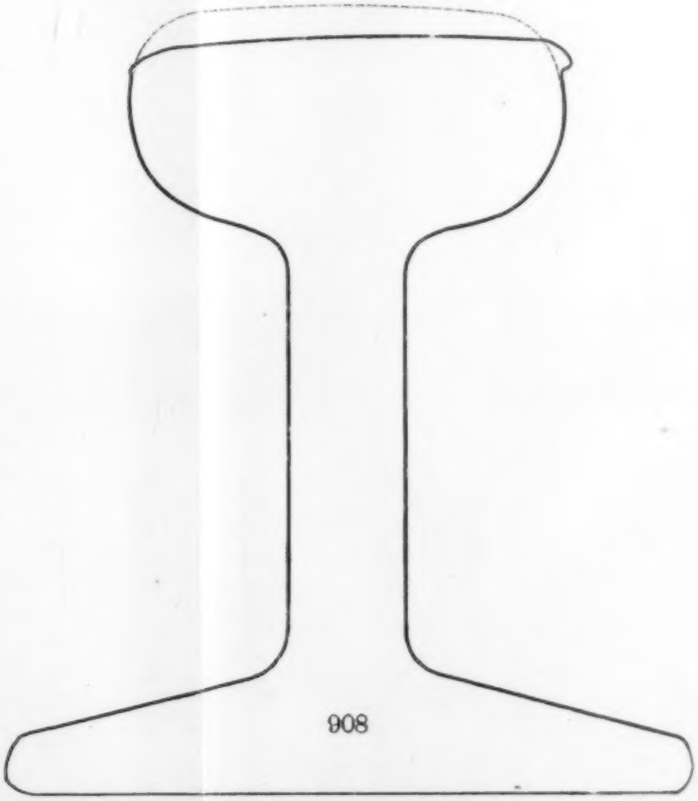

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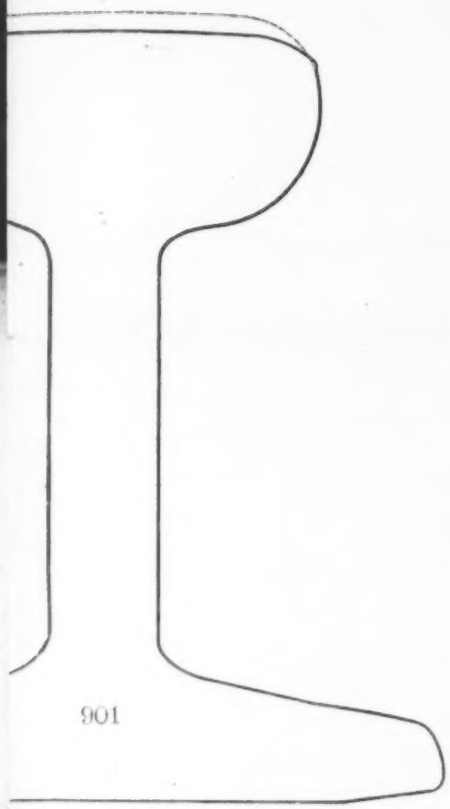

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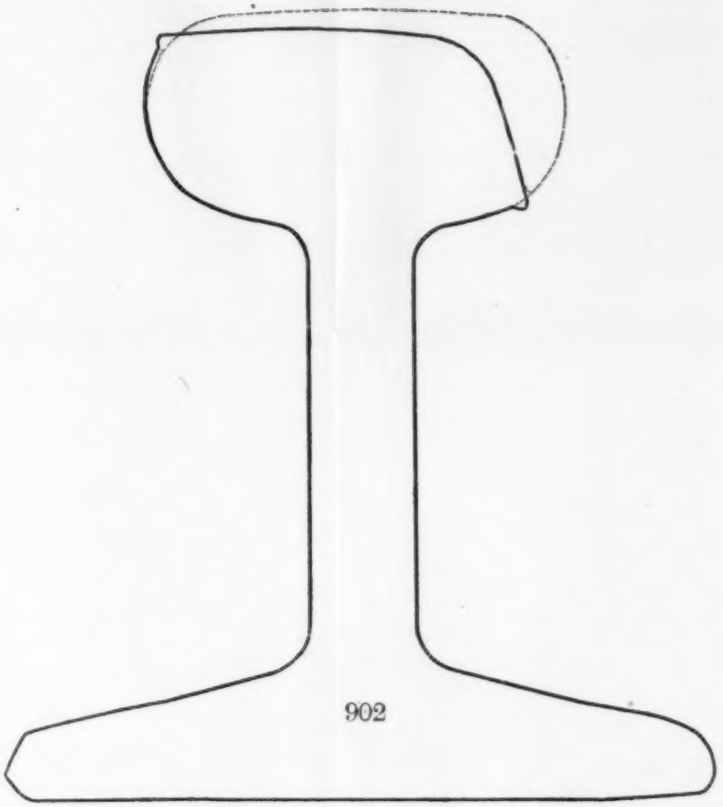

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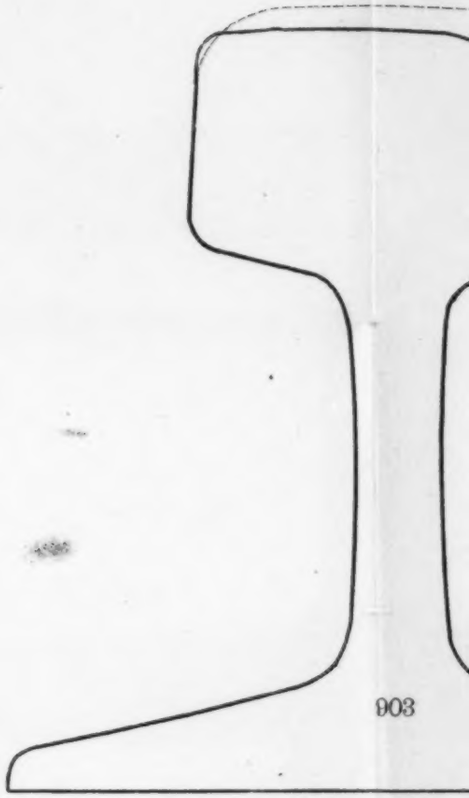

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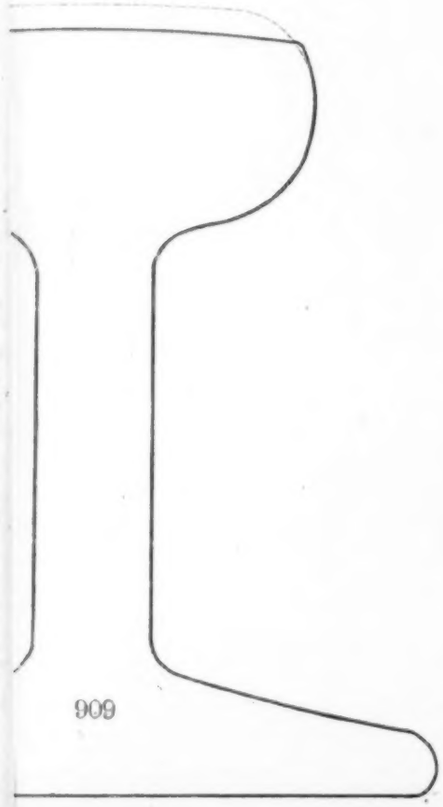

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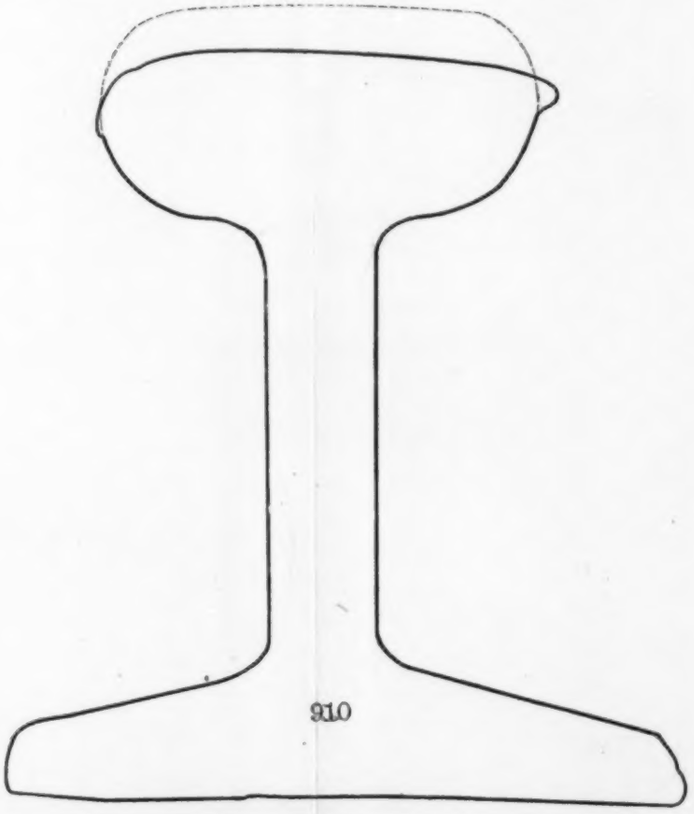

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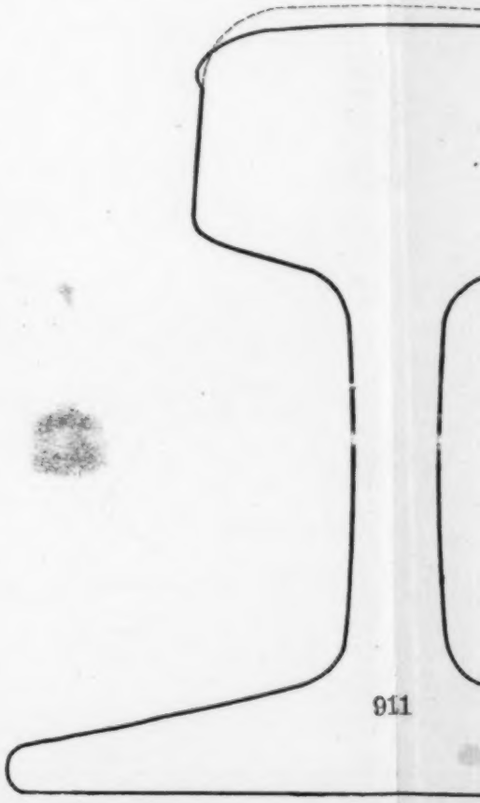

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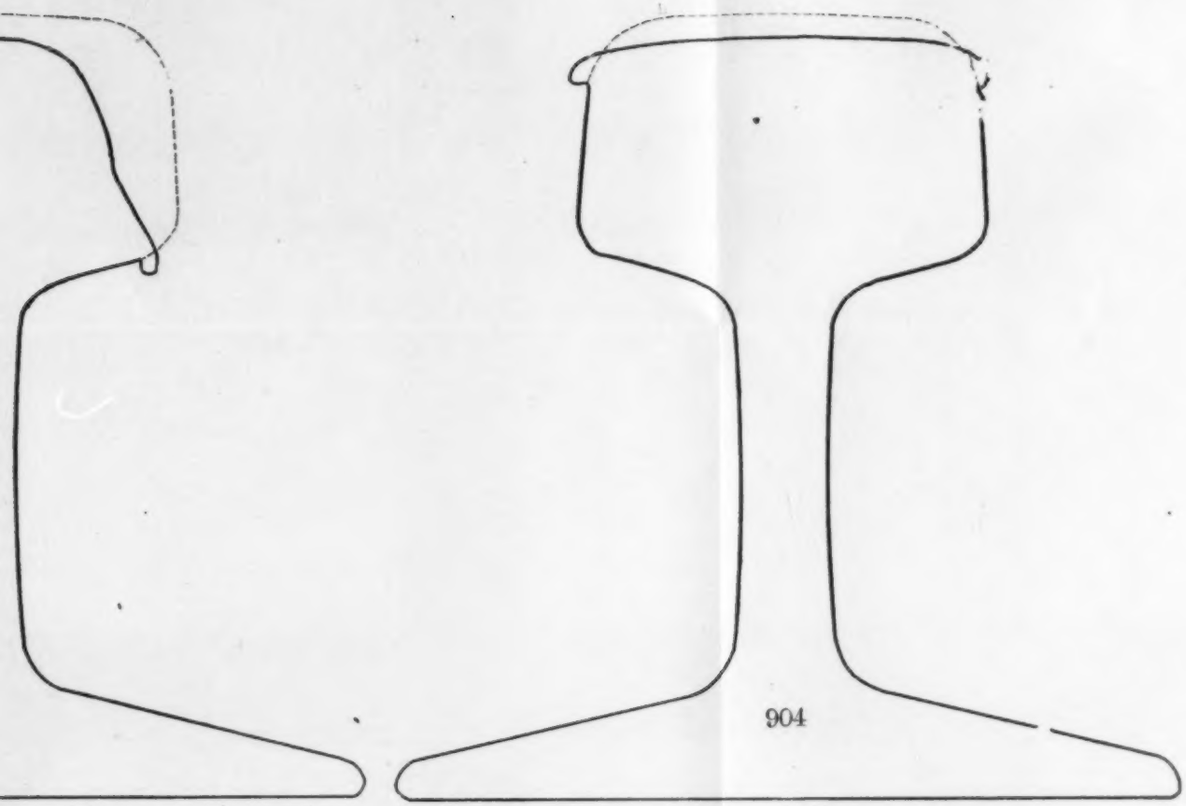

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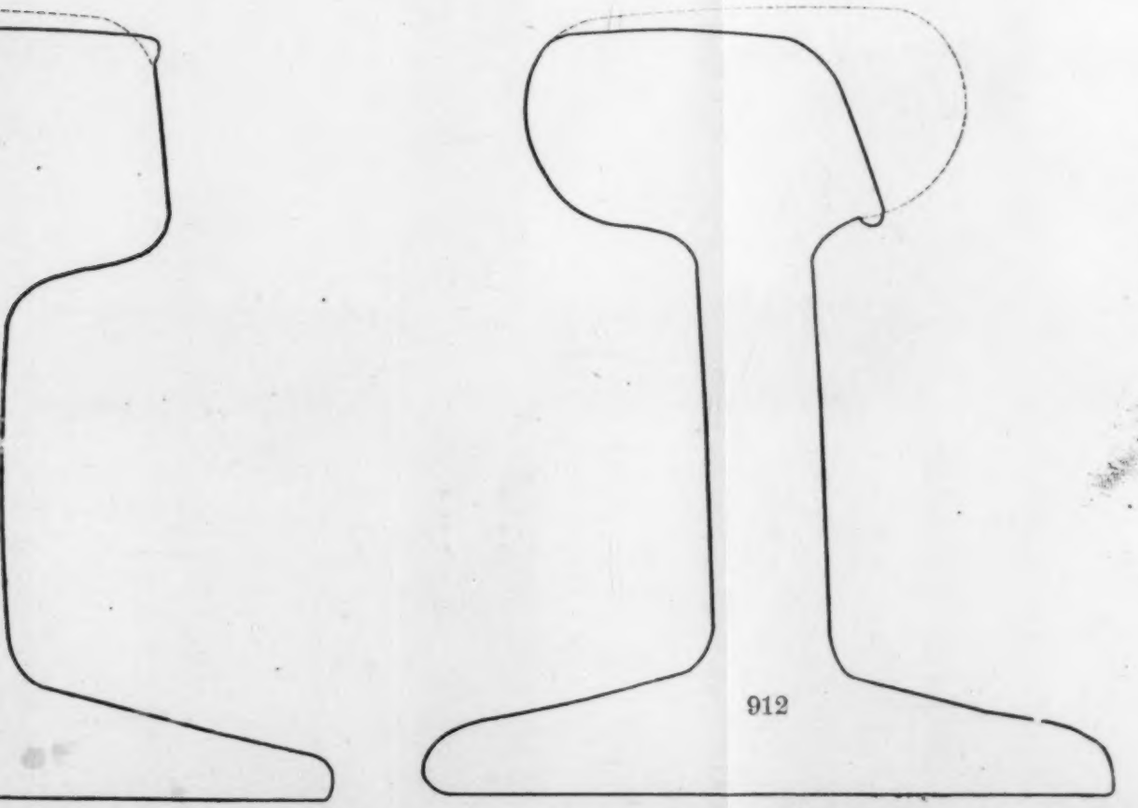

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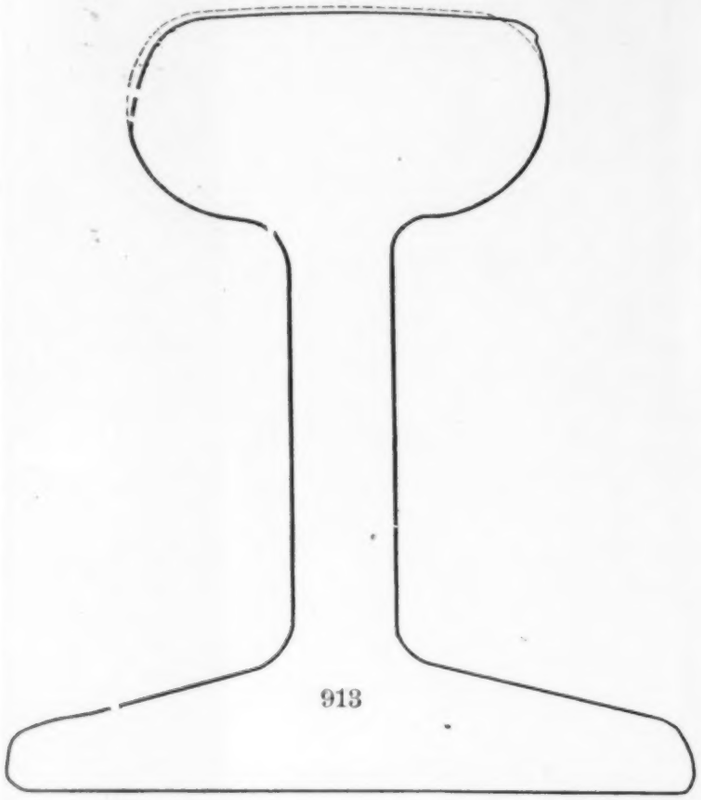

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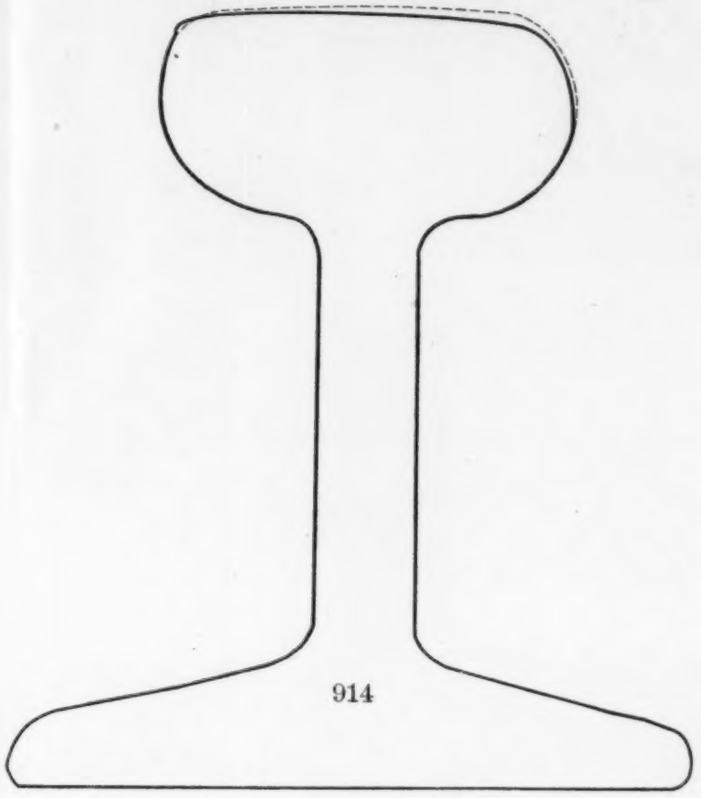

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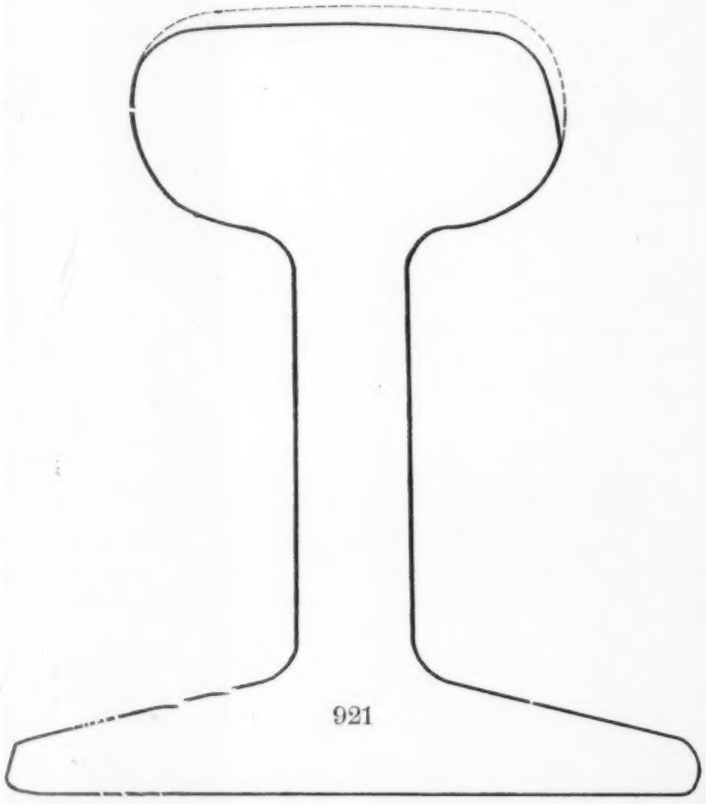

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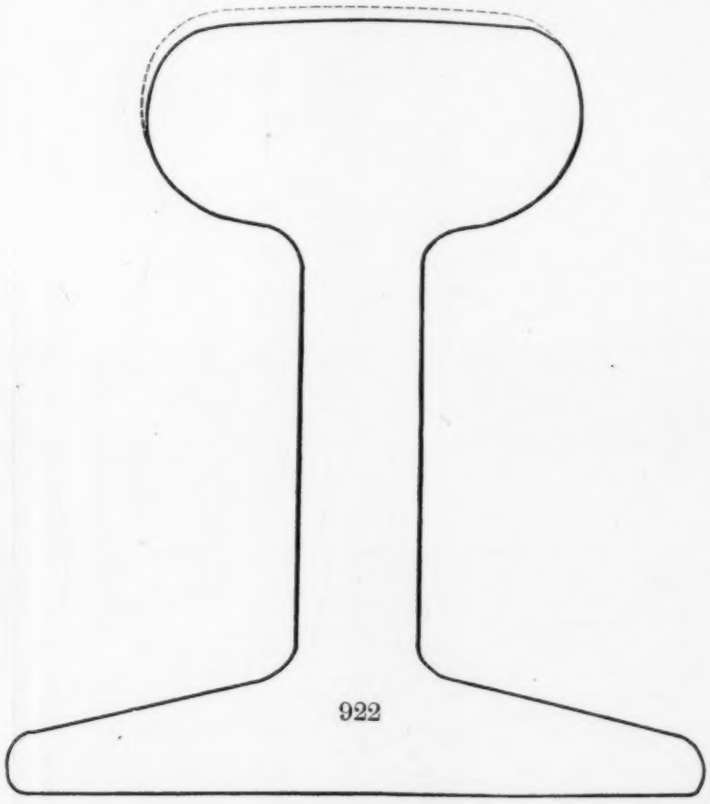

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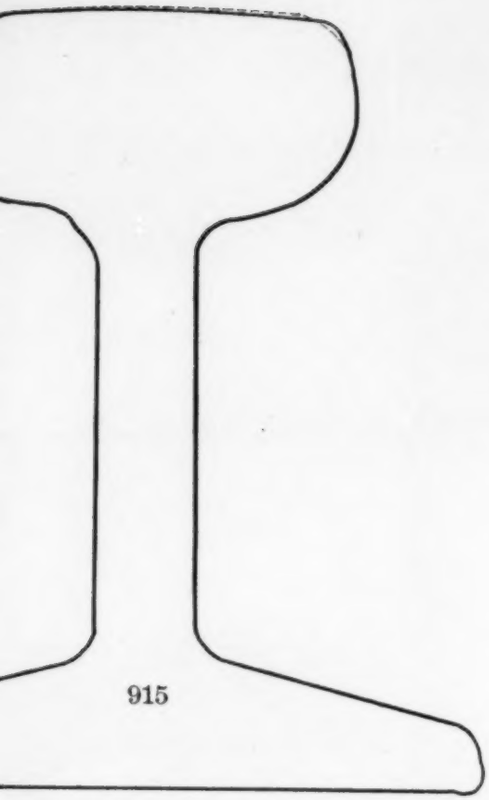

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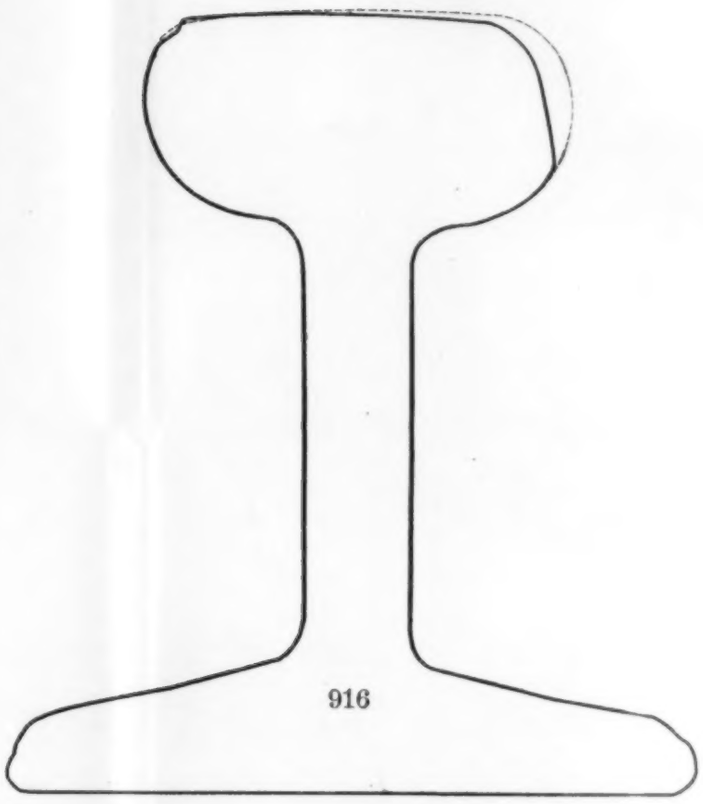

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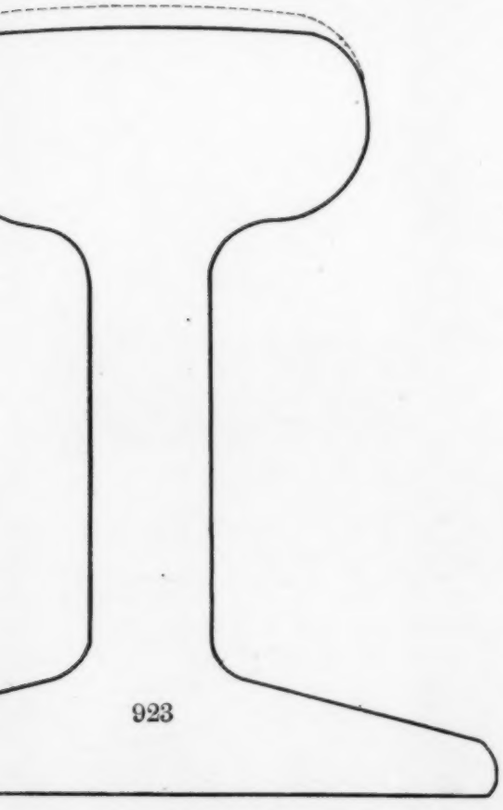

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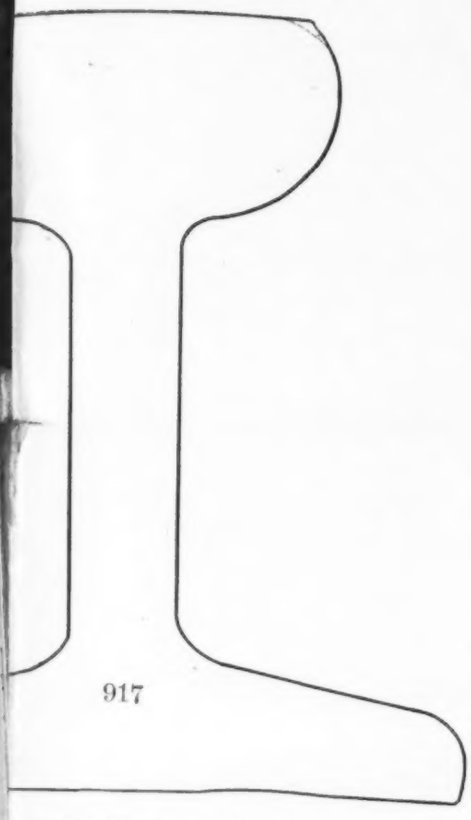

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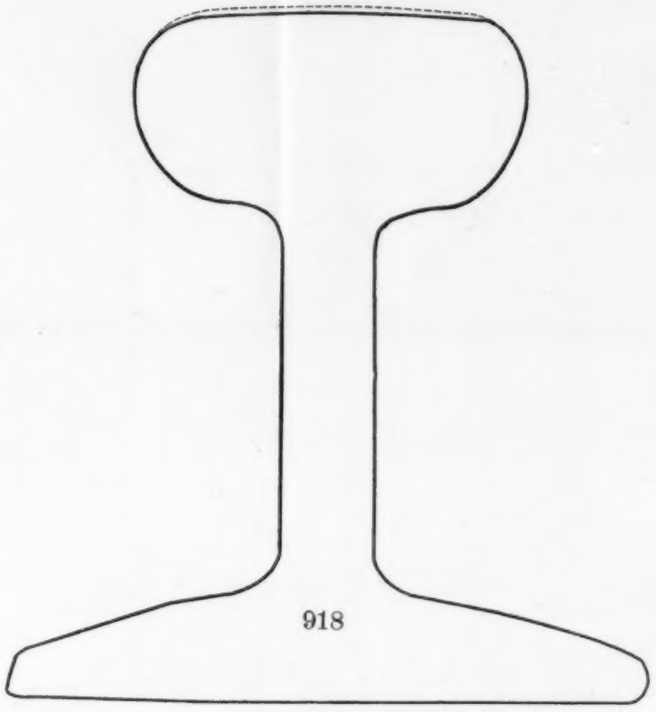

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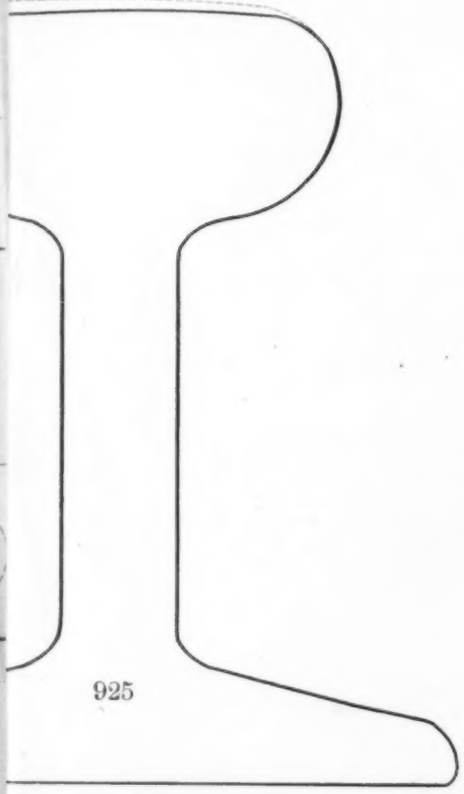

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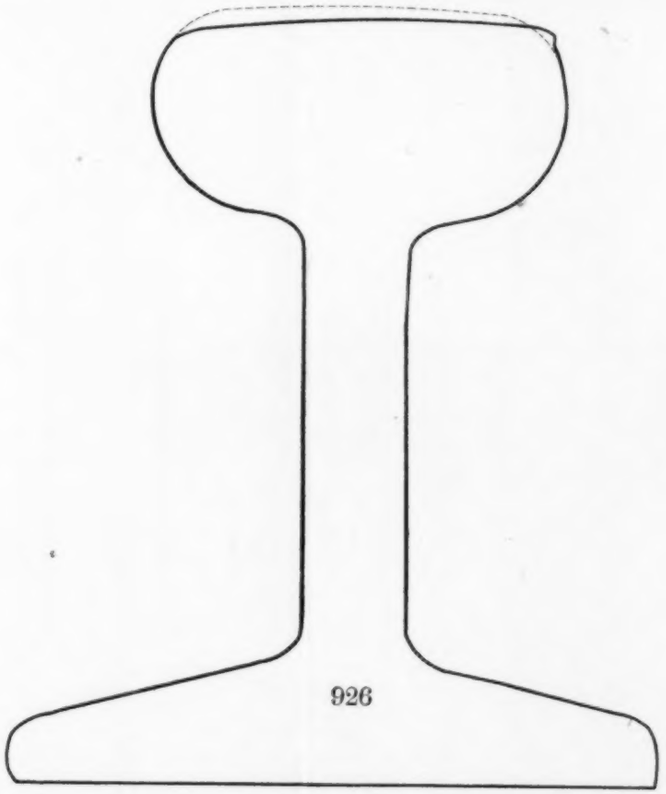

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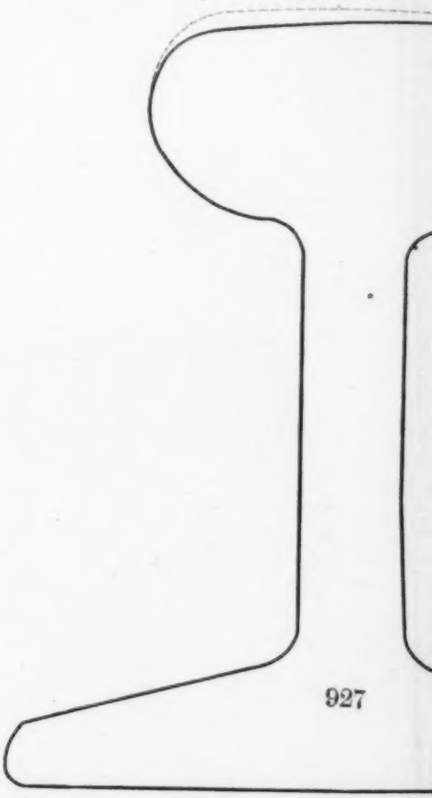

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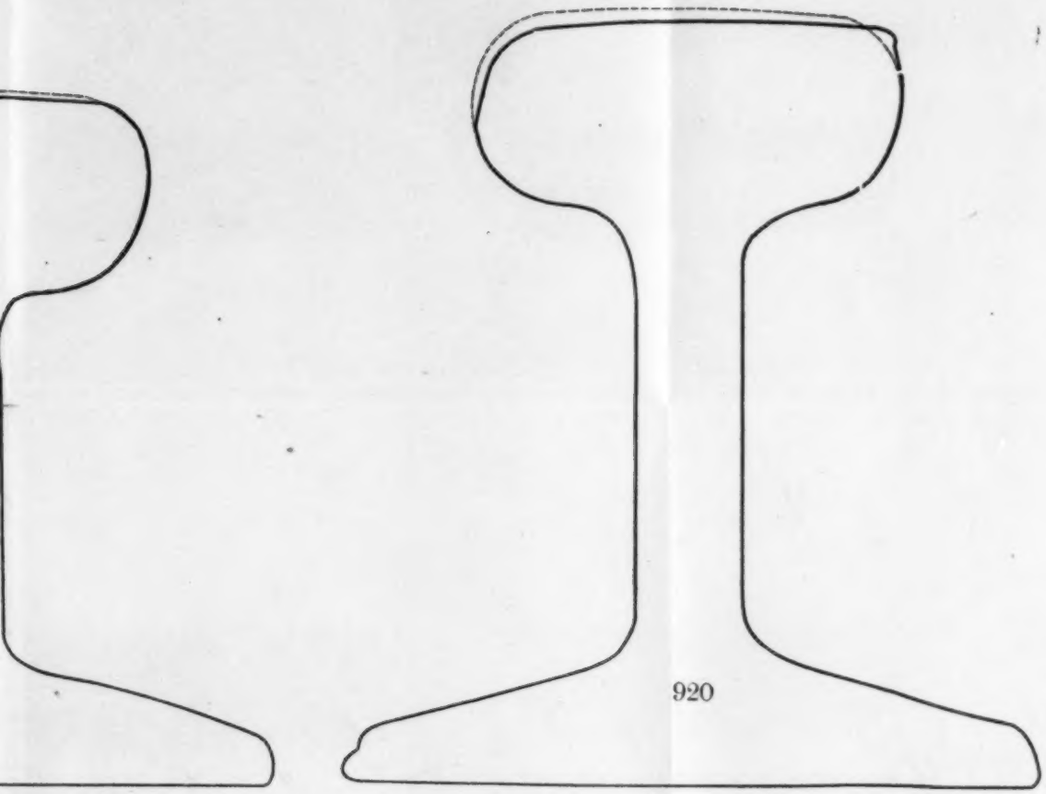
Plate 4.



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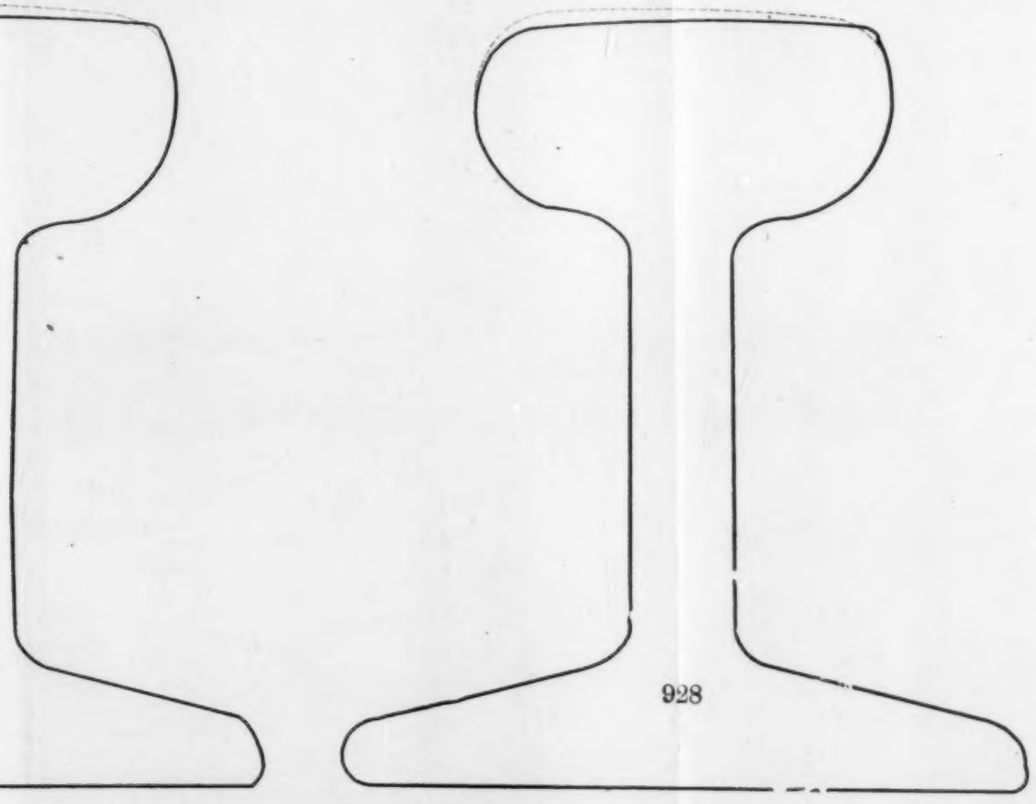

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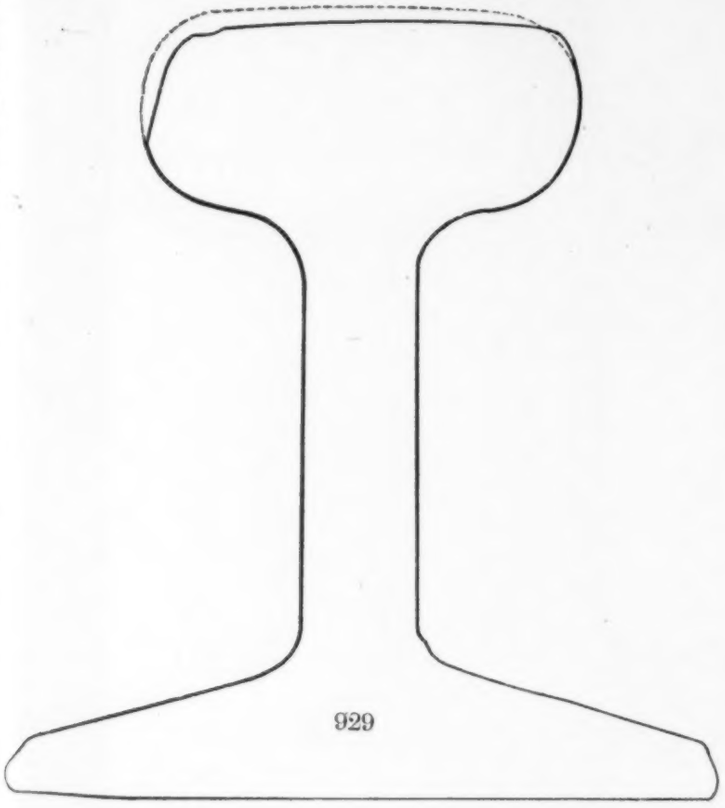

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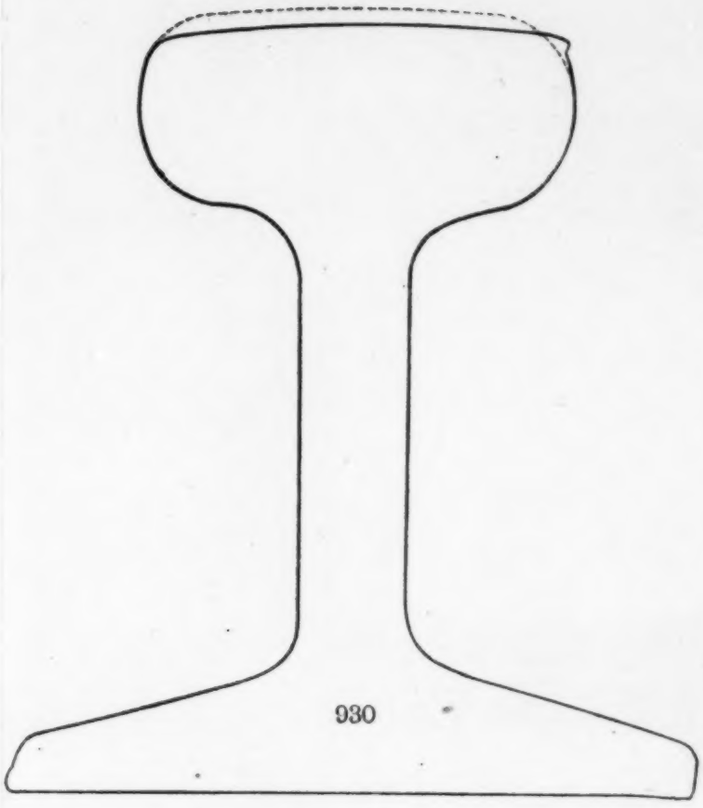

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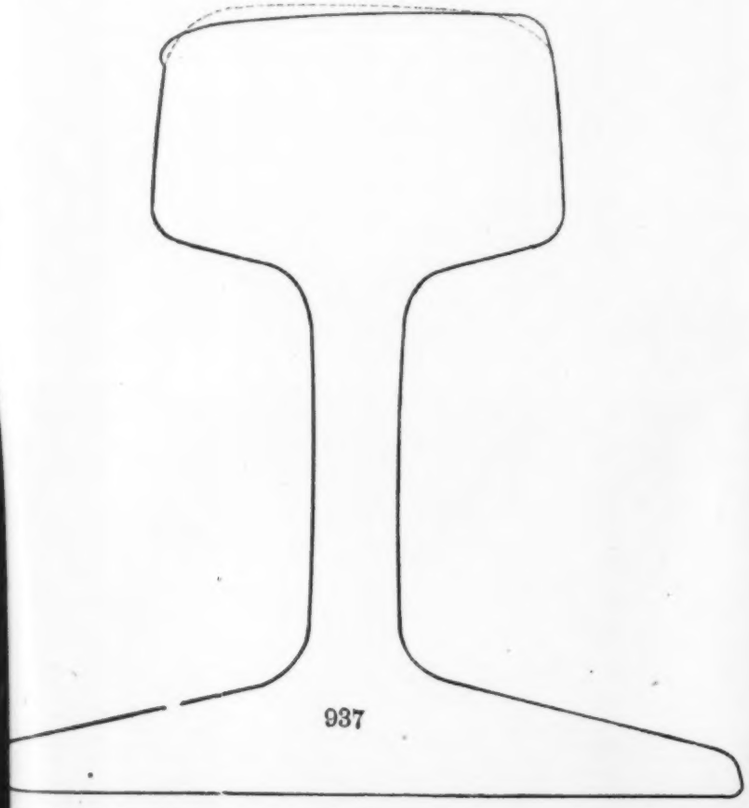

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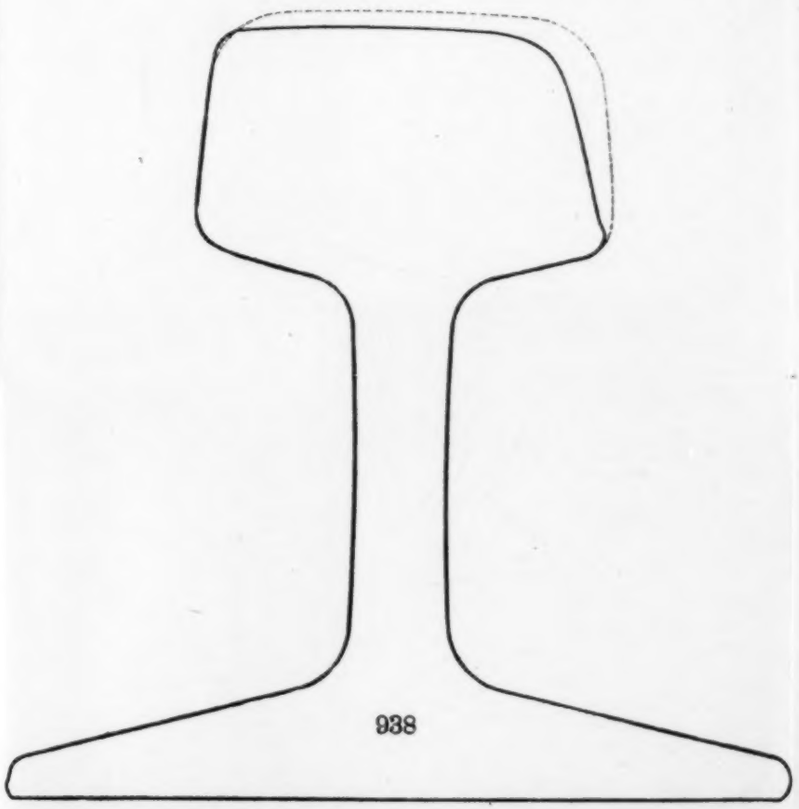
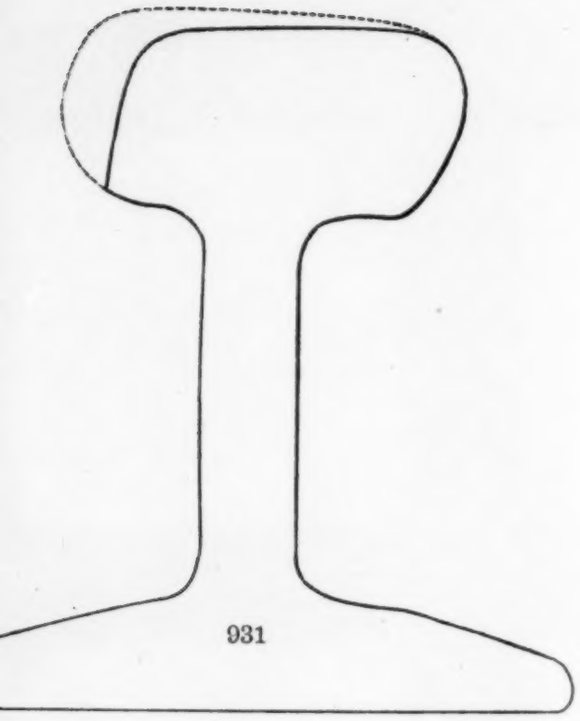


938

Diagrams of Rails on Level Curves.



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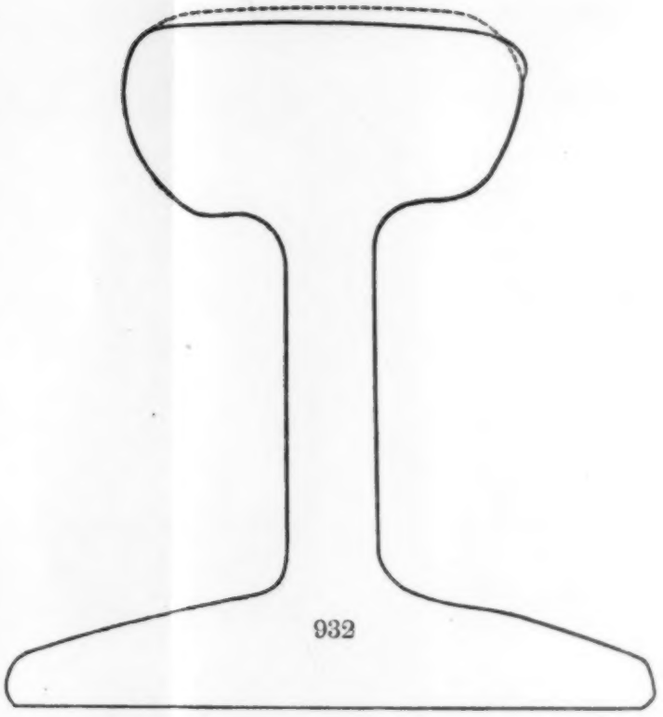

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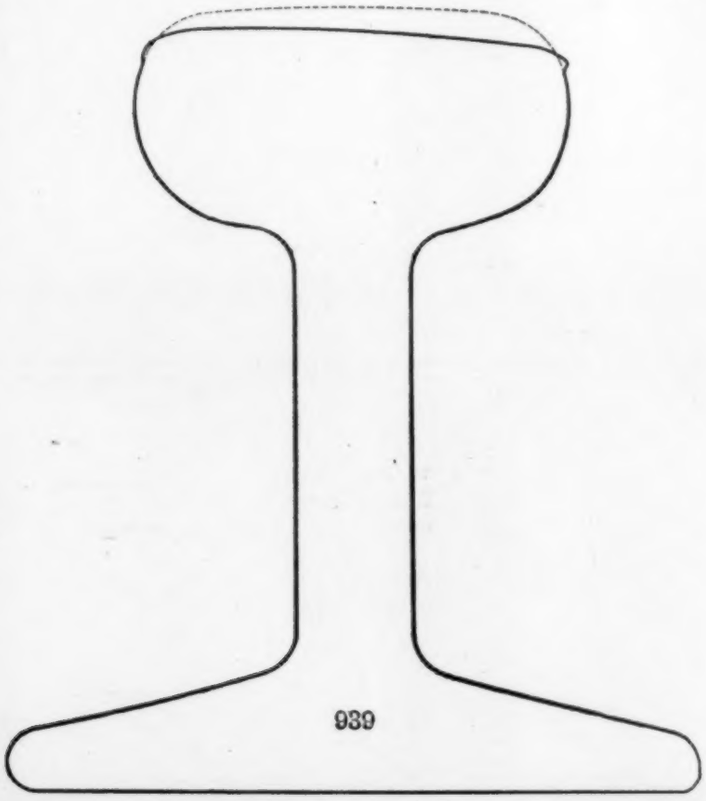

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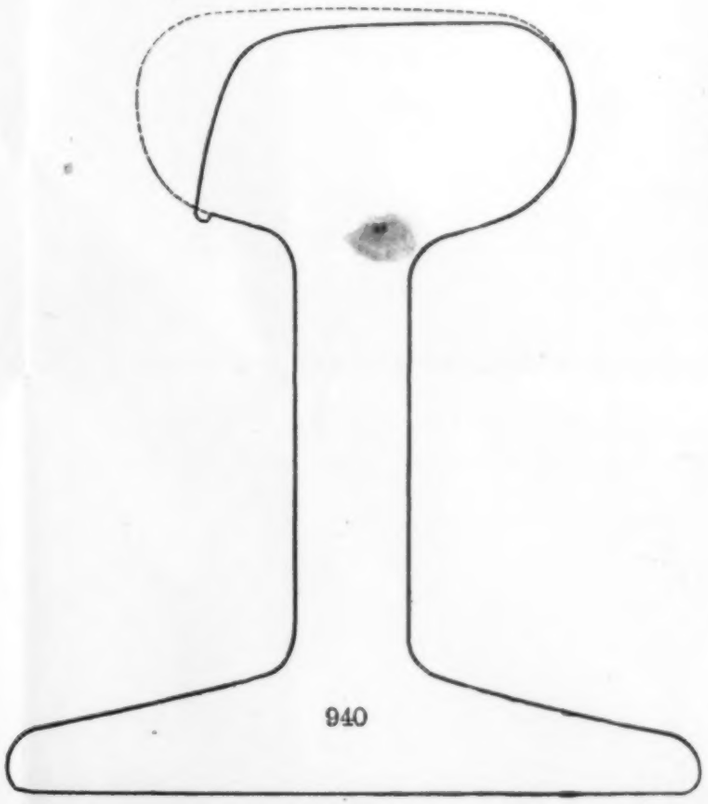

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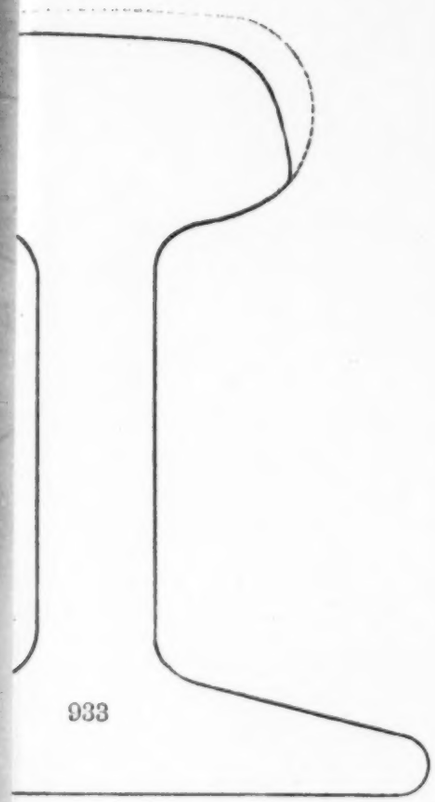

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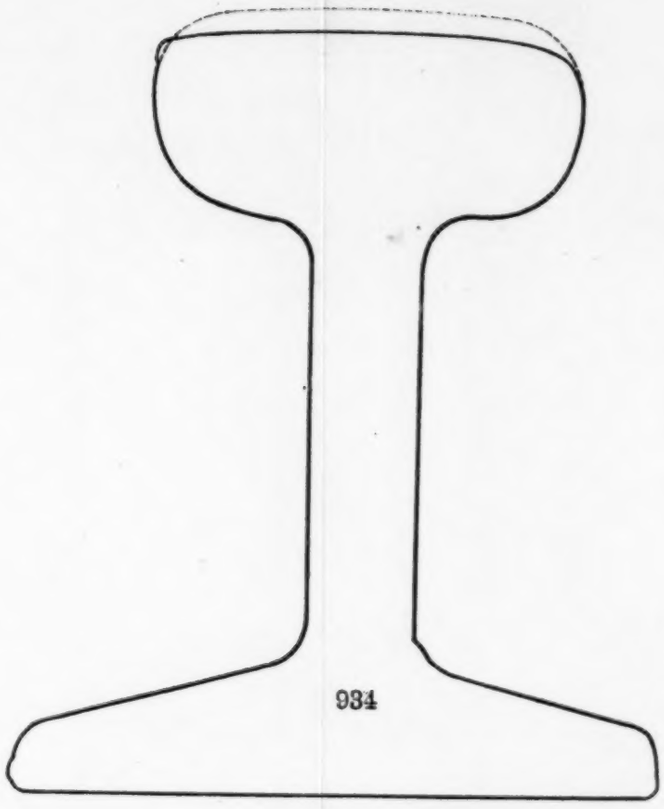

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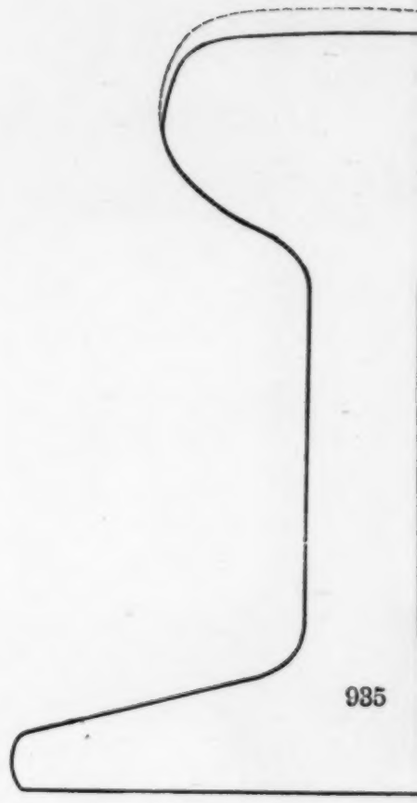

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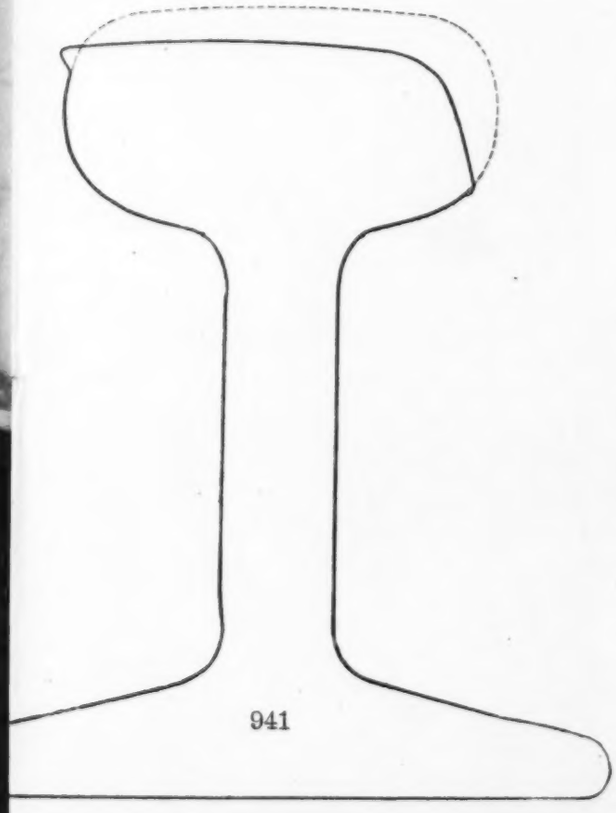

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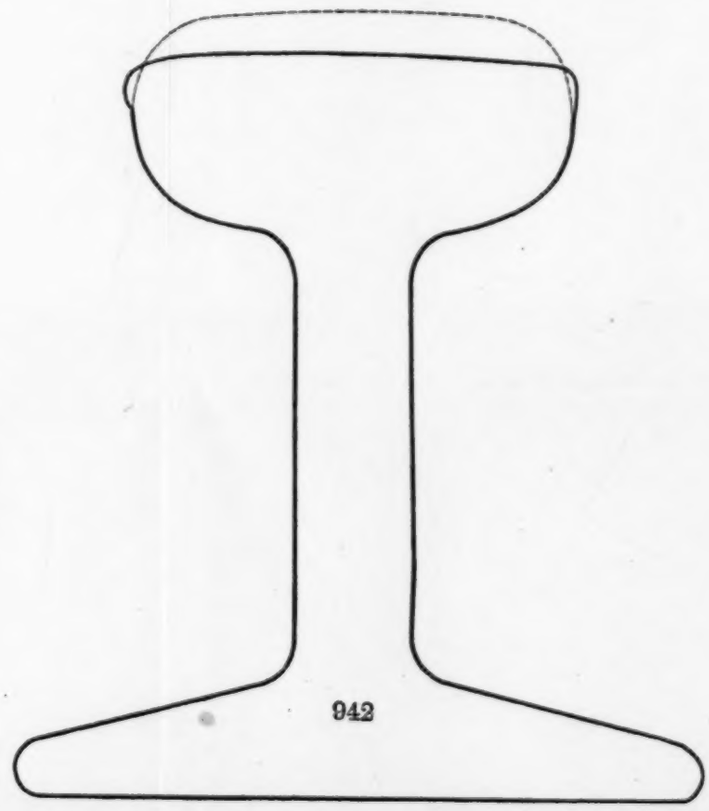
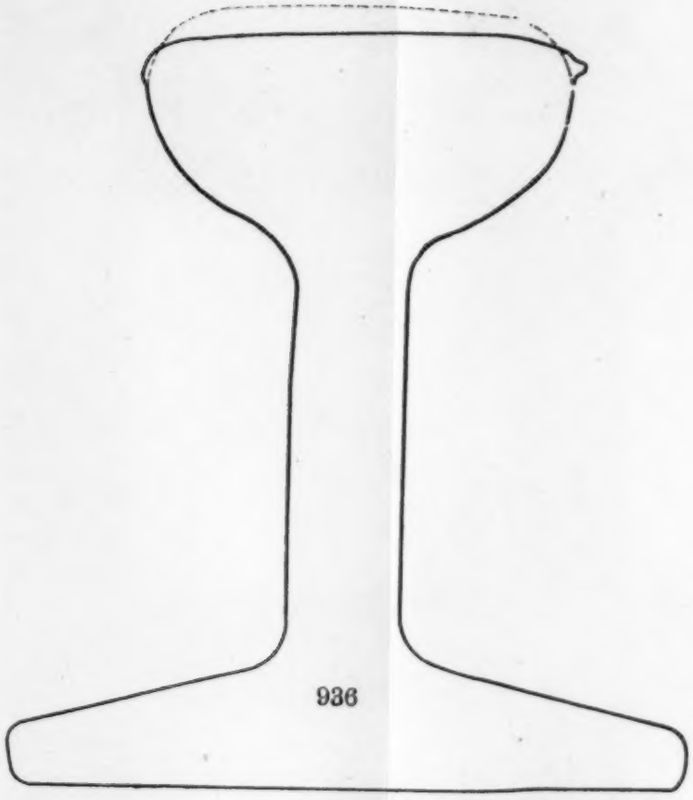
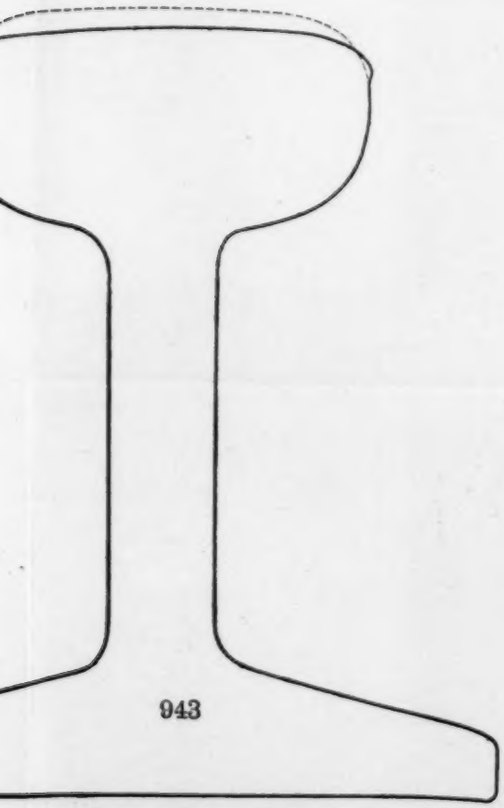
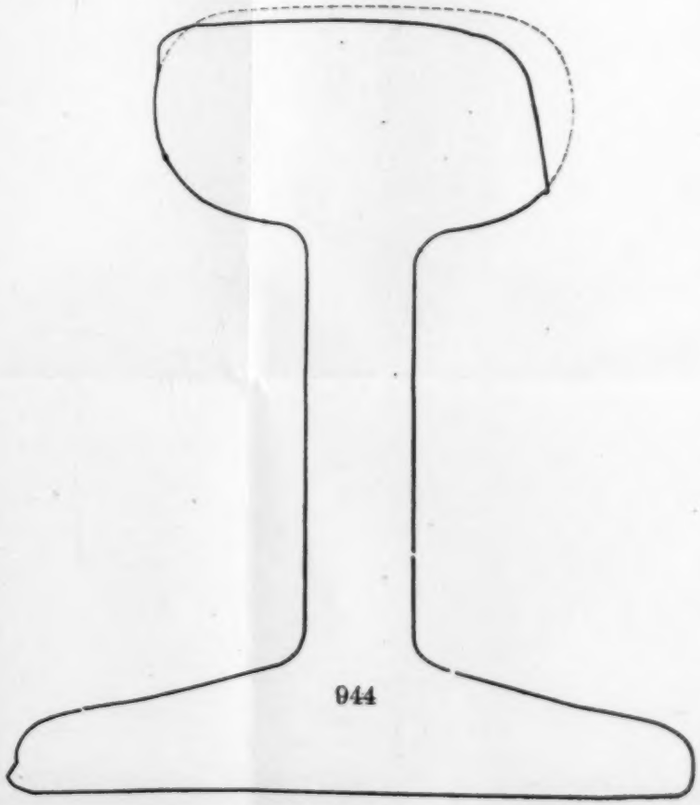


942

Plate 5.







Service.		No.	Time of service.	Track.	Degree of curve.	Grade.	WEIGHTS PER YARD.			Tonnage.	Loss per million tons.	TORSION TESTS.				UNANNEALED.	
							Original.	Present.	Loss.			Height of diagram.	Length of diagram.	Elastic limit.	Area of diagram.	Tensile strength.	Elastic limit.
TANGENT, GRADE, AGAINST TRAFFIC.		887	11 yrs.	North.		89.76	66.79	64.66	2.13	55,197,994	.0386	2.78	18.13	0.95	41.85	69,000	34,000
		884	10 yrs. 2 mos.	"		95.04	68.73	66.60	2.13	52,174,969	.0408	3.03	14.73	1.03	36.37	75,000	36,000
		883	10 yrs. 2 mos.	"		95.04	67.87	65.43	2.54	52,174,969	.0487	3.20	10.89	1.16	28.79	77,000	36,000
		885	11 yrs.	"		89.76	68.21	65.47	2.74	55,197,994	.0496	3.24	13.30	1.19	36.02	84,000	39,000
		891	7 yrs. 1 mo.	South.		40.13	67.14	64.00	3.14	53,687,192	.0585	3.16	13.68	1.11	35.79	79,000	34,000
		888	11 yrs.	North.		89.76	64.22	60.78	3.44	55,197,994	.0623	2.79	21.74	1.10	51.00	66,000	33,000
		892	7 yrs. 1 mo.	South.		40.13	68.15	64.69	3.46	53,687,192	.0644	3.24	15.94	1.10	43.13	79,000	33,000
		881	11 yrs. 1 mo.	North.		92.40	69.03	65.18	3.85	55,546,811	.0693	4.00	10.95	1.54	37.75	108,000	56,000
		894	5 yrs. 2 mos.	South.		52.80	67.47	64.54	2.93	38,088,574	.0769	3.55	8.46	1.37	25.96	93,000	45,000
		889	5 yrs. 11 mos.	"		21.12	68.56	65.02	3.54	44,620,100	.0793	3.05	14.48	1.17	37.92	76,000	36,000
		895	5 yrs. 2 mos.	"		52.80	67.92	64.89	3.03	38,088,572	.0796	3.39	5.47	1.48	15.42	60,000	30,000
		896	5 yrs. 2 mos.	"		52.80	68.46	65.42	3.04	38,088,572	.0798	3.61	12.05	1.76	36.79	93,000	40,000
		886	11 yrs.	North.		89.76	65.72	61.24	4.48	55,197,994	.0811	3.04	12.29	1.11	30.84	78,000	34,000
		890	5 yrs. 11 mos.	South.		21.12	69.79	66.15	3.64	44,620,100	.0816	3.37	12.65	1.20	36.77	85,000	36,000
		882	11 yrs. 1 mo.	North.		92.40	68.36	62.58	5.78	55,546,811	.1040	2.99	14.68	1.03	36.37	76,000	34,000
		893	5 yrs. 2 mos.	South.		21.12	68.45	64.39	4.06	38,088,572	.1066	3.37	12.92	1.14	37.15	89,000	38,000
CURVE, GRADE, WITH TRAFFIC.	LOW SIDE.	899	11 yrs. 2 mos.	North.	5	21.12	64.18	61.94	2.24	52,370,617	.0428	2.72	18.32	1.01	41.68	68,000	30,000
		900	11 yrs. 2 mos.	"	5	21.12	64.46	62.02	2.44	52,370,617	.0466	3.16	11.19	1.16	29.96	84,000	34,000
		901	7 yrs. 11 mos.	"	5	39.60	68.26	66.03	2.23	40,061,230	.0556	2.72	15.73	1.03	36.01	68,000	32,000
		906	10 yrs. 10 mos.	"	5	47.52	67.68	63.82	3.86	50,648,939	.0762	2.94	17.41	1.05	41.96	71,000	33,000
		910	8 yrs.	South.	5	89.76	67.28	61.30	5.98	62,813,664	.0952	3.07	11.31	1.14	28.41	79,000	33,000
		904	2 yrs. 11 mos.	"	5	39.60	67.85	65.63	2.22	21,504,824	.1032	3.06	13.07	1.03	33.11	79,000	33,000
		911	2 yrs. 3 mos.	"	5	89.76	68.05	66.23	1.82	17,226,993	.1056	3.64	3.21	1.64	9.12	68,000	48,000
		908	4 yrs. 2 mos.	"	4	95.04	68.19	64.44	3.75	32,428,614	.1156	3.25	9.43	1.19	25.88	81,000	39,000
	HIGH SIDE.	902	7 yrs. 11 mos.	North.	5	39.60	67.12	62.25	4.87	40,061,230	.1215	3.01	13.04	1.00	32.13	79,000	38,000
		905	10 yrs. 10 mos.	"	5	47.52	64.92	58.32	6.60	50,648,939	.1303	2.93	14.06	1.11	35.12	74,000	33,000
		909	4 yrs. 2 mos.	South.	4	95.04	67.72	63.47	4.25	32,428,614	.1310	2.52	3.56	1.62	9.99	76,000	42,000
		898	11 yrs. 2 mos.	North.	5	21.12	65.05	58.06	6.99	52,370,617	.1335	2.96	13.75	1.08	35.07	74,000	33,000
		897	11 yrs. 2 mos.	"	5	21.12	64.49	57.18	7.31	52,370,617	.1396	3.24	11.65	1.25	32.43	82,000	36,000
		912	6 yrs.	South.	5	95.04	68.29	59.78	8.51	47,438,145	.1794	3.45	11.74	1.31	33.98	91,000	38,000
		907	4 yrs. 10 mos.	North.	5	47.52	65.71	59.72	5.99	24,211,147	.2474	3.53	13.04	1.33	38.82	90,000	40,000
		903	2 yrs. 11 mos.	South.	5	39.60	68.28	61.39	6.89	21,504,824	.3204	2.57	7.36	1.04	16.10	71,000	34,000

TENSILE TESTS.					SHEARING TESTS.		BENDING TESTS.		CHEMICAL ANALYSES.					
ALED.		ANNEALED.												
stic it.	Elonga-tion.	Tensile strength.	Elastic limit.	Elonga-tion.	Shearing stress.	Detru-sion.	Maximum load.	Deflec-tion.	Carbon.	Phos-phorus.	Silicon.	Man-ganese.	Phosphorus units.	Density.
000	25	67,000	28,000	24	49,000	.1000	2770	190°	.287	.048	.023	.435	24.2	.28143
000	24	74,000	33,000	22	55,000	.0875	3090	190°	.279	.082	.043	.656	32.7	.28214
000	4	86,000	36,000	12	62,700	.0925	3090	190°	.352	.104	.029	.610	35.7	.28214
000	20	81,000	37,000	21	57,000	.0950	3110	190°	.368	.057	.130	.472	33.9	.28143
000	24	78,000	35,000	21	55,500	.1000	3140	70°	.305	.133	.022	.656	37.7	.28157
000	24	65,000	28,000	25	50,000	.1150	2670	190°	.208	.038	.074	.344	21.3	.28129
000	21	77,000	37,000	21	58,000	.0825	3230	72½°	.307	.114	.018	.542	33.7	.28229
000	15	98,000	52,000	18	68,500	.0950	4260	86°	.483	.035	.480	.782	57.2	.28143
000	5	82,000	44,000	6	70,000	.0650	3800	139°	.432	.118	.043	.880	45.9	.28086
000	21	75,000	40,000	22	56,000	.0875	3030	137°	.298	.085	.067	.568	33.1	.28114
000	1	56,000	40,000	1	64,500	.0675	3610	118½°	.470	.111	.063	.784	45.5	.28057
000	20	89,000	40,000	17	63,000	.0800	3620	35°	.415	.097	.063	.694	40.5	.28200
000	19	75,000	28,000	19	55,000	.0900	2790	190°	.349	.069	.026	.404	27.9	.28243
000	21	83,000	36,000	19	60,500	.0750	3360	113°	.365	.126	.059	.702	41.7	.28100
000	21	73,000	30,000	23	53,500	.0925	2870	179°	.320	.060	.055	.442	28.1	.28143
000	17	86,000	39,000	11	61,500	.0825	3480	156°	.387	.091	.032	.893	41.1	.28214
000	25	65,000	28,000	26	51,000	.0925	2620	190°	.263	.051	.038	.326	22.3	.28214
000	17	82,000	32,000	16	59,500	.0875	3080	184½°	.428	.030	.059	.598	32.2	.28243
000	24	67,000	32,000	24	51,500	.1000	2490	190°	.233	.083	.027	.372	24.9	.28229
000	24	69,000	25,000	22	51,500	.0875	2870	190°	.308	.053	.057	.462	27.5	.28214
000	22	75,000	28,000	16	55,500	.0875	2660	190°	.343	.098	.020	.478	31.8	.28114
000	16	77,000	34,000	16	56,000	.0875	2810	190°	.361	.100	.035	.552	34.7	.28100
000	1	69,000	30,000	1	73,500	.0550	3760	140°	.618	.154	.039	1.044	58.8	.28143
000	7	75,000	30,000	5	60,000	.0850	3350	175½°	.430	.158	.032	.552	42.7	.28129
000	8	76,000	28,000	14	57,500	.0925	2640	111°	.322	.077	.026	.492	29.5	.28214
000	20	70,000	30,000	22	54,500	.0850	2710	174°	.342	.026	.044	.460	25.4	.28243
000	2	78,000	44,000	2	73,500	.0700	3420	50°	.600	.145	.041	.680	42.1	.28086
000	21	71,000	34,000	23	53,000	.0875	2670	170°	.358	.040	.028	.538	28.1	.28157
000	18	80,000	32,000	17	59,500	.0800	2800	170°	.431	.049	.046	.582	33.2	.28186
000	10	88,000	50,000	12	61,500	.0750	3750	103°	.401	.083	.056	.816	40.8	.28157
000	21	86,000	44,000	20	62,000	.0850	3580	101°	.350	.102	.124	.748	43.1	.28200
000	9	69,000	34,000	12	55,500	.0975	2860	190°	.355	.108	.029	.490	33.8	.28114

Service.		No.	Time of service.	Track.	Degree of curve.	WEIGHTS PER YARD.			Tonnage.	Loss per million tons.	TORSION TESTS.				T		
						Original.	Present.	Loss.			Height of diagram.	Length of diagram.	Elastic limit.	Area of diagram.	UNANNEALED. Tensile strength.	Elastic limit.	El t
LEVEL TANGENT.		917	6 yrs.	North.		67.14	66.94	0.20	31,127,829	.0064	3.59	11.86	1.45	36.34	93,000	42,000	
		919	10 yrs. 6 mos.	North.		55.61	55.10	0.51	51,720,011	.0098	2.72	17.22	1.07	39.20	64,000	32,000	
		918	10 yrs. 6 mos.	North.		55.91	55.20	0.71	51,720,011	.0137	2.89	17.92	1.21	43.29	70,000	34,000	
		915	6 yrs. 1 mo.	North.		64.91	64.40	0.51	31,514,889	.0162	2.21	7.75	1.01	15.17	71,000	34,000	
		926	9 yrs. 3 mos.	South.		64.96	63.43	1.53	76,409,123	.0200	3.05	16.97	1.22	42.56	73,000	40,000	
		913	9 yrs. 4 mos.	North.		65.52	64.51	1.01	45,855,101	.0220	3.13	12.18	1.16	32.20	72,000	39,000	
		927	9 yrs. 3 mos.	South.		64.98	63.25	1.73	76,409,123	.0226	3.07	19.01	1.55	48.91	72,000	40,000	
		914	9 yrs. 4 mos.	North.		64.78	63.46	1.32	45,855,101	.0288	2.60	10.80	.97	23.28	64,000	32,000	
		928	5 yrs.	South.		66.25	64.93	1.32	43,610,150	.0303	2.98	3.37	1.32	8.29	60,000	44,000	
		920	11 yrs. 7 mos.	North.		67.61	65.78	1.83	52,991,684	.0345	2.95	18.27	1.00	43.99	69,000	32,000	
		924	4 yrs. 1 mo.	South.		68.31	66.79	1.52	36,349,989	.0418	3.67	12.64	1.37	39.71	93,000	39,000	
		916	6 yrs.	North.		67.25	65.83	1.42	31,127,829	.0456	3.18	10.67	1.25	28.47	83,000	39,000	
		925	4 yrs. 1 mo.	South.		68.36	66.63	1.73	36,349,989	.0476	3.70	14.95	1.36	47.58	92,000	40,000	
		922	5 yrs. 4 mos.	North.		69.04	67.01	2.03	27,622,230	.0735	3.74	12.57	1.37	39.97	94,000	39,000	
		923	6 yrs. 1 mo.	North.		68.58	65.66	2.92	31,514,889	.0926	2.21	4.55	1.08	10.59	64,000	34,000	
		921	5 yrs. 4 mos.	North.		67.23	64.18	3.05	27,622,230	.1104	3.34	11.68	1.20	33.19	84,000	37,000	
LEVEL CURVE.	LOW SIDE.	932	10 yrs. 6 mos.	North.	3	56.17	54.95	1.22	51,720,011	.0236	2.92	16.53	1.09	39.40	69,000	34,000	
		937	3 yrs. 4 mos.	South.	2	66.77	65.96	0.81	29,905,122	.0271	3.00	4.84	1.34	12.12	68,000	38,000	
		936	12 yrs. 9 mos.	South.	2	68.02	65.17	2.85	92,025,478	.0309	3.01	15.56	1.05	38.72	72,000	34,000	
		930	11 yrs. 7 mos.	North.	2¼	66.38	64.65	1.73	52,991,684	.0327	3.03	14.77	1.04	36.94	73,000	31,000	
		934	9 yrs. 8 mos.	South.	3½	67.14	64.09	3.05	78,364,968	.0389	2.95	13.89	1.26	34.43	74,000	39,000	
		943	6 yrs. 3 mos.	South.	2	66.84	64.30	2.54	55,127,464	.0461	3.04	16.05	1.10	41.08	74,000	34,000	
		939	4 yrs. 2 mos.	South.	4	68.11	65.27	2.84	37,150,179	.0764	3.76	7.63	1.47	24.51	90,000	40,000	
		942	4 yrs. 10 mos.	South.	3	67.93	62.67	5.26	42,277,638	.1244	3.52	5.38	1.60	15.48	90,000	48,000	
	HIGH SIDE.	935	12 yrs. 9 mos.	South.	2	68.19	64.93	3.26	92,025,478	.0354	3.30	11.80	1.14	32.70	86,000	39,000	
		929	11 yrs. 7 mos.	North.	2¼	68.89	66.45	2.44	52,991,684	.0460	2.89	16.28	1.18	39.95	69,000	36,000	
		933	9 yrs. 8 mos.	South.	3½	67.61	63.15	4.46	78,364,968	.0569	3.16	8.19	1.20	21.91	82,000	38,000	
		944	6 yrs. 3 mos.	South.	2	66.72	63.47	3.25	55,127,464	.0589	3.00	6.78	1.24	16.68	75,000	34,000	
		931	10 yrs. 6 mos.	North.	3	57.09	52.61	4.48	51,720,011	.0866	2.81	17.70	1.10	42.24	66,000	34,000	
		938	3 yrs. 4 mos.	South.	2	68.70	64.85	3.85	29,905,122	.1287	3.06	12.16	1.02	29.53	79,000	36,000	
		941	4 yrs. 10 mos.	South.	3	66.92	60.83	6.09	42,277,638	.1440	3.43	13.88	1.25	40.30	87,000	39,000	
		940	4 yrs. 2 mos.	South.	4	68.17	61.77	6.40	37,150,179	.1723	3.80	5.38	1.62	16.73	76,000	52,000	

TENSILE TESTS.						SHEARING TESTS.		BENDING TESTS.		CHEMICAL ANALYSES.					
ED.		ANNEALED.													
e	Elongation.	Tensile strength.	Elastic limit.	Elongation.		Shearing stress.	Detrusion.	Maximum load.	Deflection.	Carbon.	Phosphorus.	Silicon.	Manganese.	Phosphorus units.	Density.
0	19	89,000	45,000	18		65,000	.080	2930	13°	.423	.127	.083	.708	45.1	.28186
0	24	62,000	30,000	25		51,500	.1025	2270	190°	.247	.041	.023	.344	20.3	.28243
0	20	69,000	35,000	24		54,500	.095	2520	190°	.219	.061	.181	.376	29.9	.28200
0	4	62,000	25,000	4		60,000	.0775	3030	184°	.368	.113	.026	.714	39.2	.28100
0	26	71,000	36,000	24		55,500	.100	2680	190°	.211	.145	.033	.352	30.2	.28271
0	7	76,000	35,000	18		58,000	.090	2630	190°	.335	.102	.036	.508	33.4	.28143
0	26	71,000	35,000	24		58,500	.0975	2710	190°	.187	.131	.049	.320	28.1	.28214
0	14	64,000	30,000	17		52,000	.100	2530	190°	.270	.108	.015	.322	26.9	.28157
0	1	68,000	50,000	2		66,000	.080	3190	173°	.428	.142	.042	.564	41.9	.28214
0	25	68,000	25,000	24		53,500	.100	2630	190°	.293	.063	.039	.326	24.6	.28200
0	20	90,000	36,000	18		66,000	.100	3550	111°	.388	.123	.059	.806	44.2	.28229
0	17	81,000	40,000	18		60,500	.0875	3010	154½°	.329	.132	.044	.554	37.5	.28171
0	13	90,000	40,000	18		66,500	.095	3980	73°	.389	.109	.069	.824	43.8	.28243
0	19	91,000	35,000	17		66,500	.090	3760	80°	.428	.109	.038	.870	44.7	.28243
0	3	54,000	34,000	2		64,500	.085	3360	155°	.452	.144	.037	.708	45.5	.27943
0	18	82,000	35,000	16		65,000	.090	3310	172°	.340	.096	.042	.746	37.9	.28257
0	20	70,000	35,000	23		57,000	.100	2340	190°	.269	.047	.026	.372	22.4	.28286
0	2	68,000	36,000	3		68,500	.085	3220	168°	.454	.145	.015	.726	44.8	.28129
0	23	70,000	26,000	22		53,500	.1025	2790	190°	.353	.039	.035	.318	23.8	.28259
0	23	70,000	25,000	22		53,500	.1000	2820	190°	.394	.035	.038	.288	24.3	.28286
0	22	74,000	35,000	22		61,000	.1025	2950	190°	.187	.144	.045	.252	27.8	.28214
0	24	71,000	38,000	24		55,500	.100	2780	159½°	.314	.061	.025	.602	29.8	.28214
0	3	95,000	41,000	6		72,000	.090	3350	20°	.579	.115	.036	.718	47.0	.28171
0	2	64,000	40,000	1		64,500	.0575	3240	108½°	.497	.136	.062	.724	47.8	.28143
0	10	82,000	30,000	20		64,000	.095	3130	142½°	.460	.045	.059	.406	30.2	.28259
0	24	70,000	35,000	24		55,500	.1125	2750	190°	.235	.055	.080	.300	23.3	.28259
0	5	67,000	35,000	3		65,000	.085	3180	186°	.376	.087	.054	.558	35.1	.28143
0	4	78,000.	33,000	8		61,500	.095	3040	105°	.441	.057	.035	.702	36.1	.28214
0	24	64,000	27,000	24		52,000	.110	2430	190°	.260	.047	.029	.416	23.1	.28229
0	16	77,000	35,000	16		59,500	.0925	2950	146°	.343	.115	.035	.594	37.5	.28143
0	19	83,000	37,000	16		63,500	.095	3290	112°	.404	.111	.065	.716	42.1	.28186
0	1	80,000	44,000	2		77,500	.0725	3220	17½°	.548	.127	.046	.680	46.9	.28214

Number of line.	Number of rails in average.	DESCRIPTION OF AVERAGES.	Loss per million tons.	Grade.	Degree of curve.	TORSION TESTS.				T	
						Height of diagram.	Length of diagram.	Elastic limit.	Area of diagram.	UNANNEALED. Tensile strength.	Elastic limit.
1	8	Grade tangent, slower wearing.	.0540	79.00		3.18	14.92	1.15	38.84	79,625	37,625
2	8	Grade tangent, faster wearing.	.0861	50.49		3.29	11.62	1.28	32.15	81,250	36,625
3	4	Grade curve, low side, slower wearing.	.0553	32.34	5°	2.89	15.66	1.06	37.40	72,750	32,250
4	4	Grade curve, low side, faster wearing.	.1049	78.54	4¼°	3.25	9.25	1.25	24.13	76,750	38,250
5	4	Grade curve, high side, slower wearing.	.1291	50.82	4¼°	2.85	11.10	1.20	28.08	75,750	36,500
6	4	Grade curve, high side, faster wearing.	.2217	50.82	5°	3.20	10.95	1.23	30.33	83,500	37,000
7	8	Level tangent, slower wearing.	.0174			2.91	14.22	1.20	35.12	72,375	36,625
8	8	Level tangent, faster wearing.	.0595			3.22	11.09	1.24	31.47	79,875	38,000
9	4	Level curve, low side, slower wearing.	.0286		2 5/16°	2.99	12.92	1.13	31.79	70,500	34,250
10	4	Level curve, low side, faster wearing.	.0715		3½°	3.32	10.74	1.36	28.87	82,000	40,250
11	4	Level curve, high side, slower wearing.	.0493		2 7/16°	3.09	10.76	1.19	27.81	78,000	36,750
12	4	Level curve, high side, faster wearing.	.1329		3°	3.28	12.28	1.25	32.20	77,000	40,250
13	24	Tangents and low sides curves, slower wearing.	.0378			3.01	14.48	1.15	36.19	74,542	35,833
14	24	Tangents and low sides curves, faster wearing.	.0779			3.27	10.90	1.28	30.04	80,167	37,958
15	8	High sides of curves, slower wearing.	.0892			2.97	10.93	1.19	27.94	76,875	36,625
16	8	High sides of curves, faster wearing.	.1773			3.24	11.61	1.24	31.27	80,250	38,625
17	32	All conditions, slower wearing.	.0506			3.00	13.59	1.16	34.13	75,125	36,031
18	32	All conditions, faster wearing.	.1028			3.26	11.08	1.27	30.35	80,188	38,125

TENSILE TESTS.					SHEARING TESTS.		BENDING TESTS.		CHEMICAL ANALYSES.					
ED.		ANNEALED.												
c	Elongation.	Tensile strength.	Elastic limit.	Elongation.	Shearing stress.	Detrusion.	Maximum load.	Deflection.	Carbon.	Phosphorus.	Silicon.	Manganese.	Phosphorus units.	Density.
5	19.6	78,250	35,750	20.5	56,962	.0959	3014	147°	.324	.076	.102	.562	34.8	.28184
5	15.6	77,375	37,125	14.7	60,500	.0800	3320	133°	.379	.095	.051	.669	87.9	.28141
0	22.5	70,750	29,250	22.	53,375	.0919	2765	188°	.308	.054	.045	.439	26.7	.28225
0	11.5	74,000	30,500	9.5	61,250	.0787	3145	174°	.438	.127	.031	.656	42.0	.28121
0	12.8	73,750	34,000	15.2	59,625	.0837	2860	126°	.405	.072	.035	.542	31.3	.28175
0	14.5	80,750	40,000	15.2	59,625	.0844	3247	141°	.384	.085	.064	.659	37.7	.28164
5	17.5	70,500	33,875	19.2	56,875	.0928	2662	167°	.282	.104	.056	.455	31.6	.28189
0	14.5	78,000	36,875	14.4	63,562	.0909	3349	138°	.381	.115	.046	.675	40.0	.28187
0	17.	69,500	30,500	17.5	58,125	.0969	2792	184°	.367	.066	.028	.426	28.8	.28240
0	12.7	76,000	38,500	13.2	63,250	.0875	3080	119°	.394	.114	.042	.574	38.1	.28185
0	10.7	74,250	33,250	13.7	61,500	.0969	3025	150°	.378	.061	.057	.491	31.2	.28219
0	15.	76,000	35,750	14.5	63,125	.0925	2972	116°	.388	.100	.044	.601	37.4	.28193
3	18.9	72,958	33,167	19.8	56,529	.0943	2818	167°	.314	.080	.065	.483	31.4	.28201
8	14.1	76,792	36,167	13.5	62,104	.0847	3260	140°	.392	.110	.044	.653	39.3	.28160
5	11.7	74,000	33,625	14.4	60,562	.0903	2942	138°	.391	.066	.046	.516	31.2	.28197
5	14.7	78,375	37,875	14.8	61,375	.0884	3109	128°	.386	.092	.054	.630	37.5	.28178
1	17.1	73,219	33,281	18.5	57,537	.0933	2878	160°	.334	.077	.060	.491	31.3	.28201
5	14.2	77,188	36,594	13.8	61,922	.0856	3222	133°	.390	.106	.047	.647	38.9	.28165